LIFE CYCLE ASSESSMENT OF PRESTRESSED CONCRETE RAILWAY BRIDGES IN HIMALAYAN REGION OF JAMMU AND KASHMIR, INDIA

A

SYNOPSIS

(THESIS PROPOSAL)

SUBMITTED TO

THE ICFAI UNIVERSITY DEHRADUN

IN PARTIAL FULFILLMENT OF THE REQUIREMENT

FOR THE AWARD OF THE DEGREE OF

DOCTOR OF PHILOSOPHY (Ph.D.)

IN

CIVIL ENGINEERING

BY

RAJESH KUMAR SINGH

(Enrollment No: RSITS230027)

Under the Supervision of

Prof. (Dr.) Ram Karan Singh

ICFAI Tech School
The ICFAI University, Dehradun

2023-24

The ICFAI University, Dehradun

Candidate's Declaration

I, **Rajesh Kumar Singh**, declare that the synopsis entitled, "***Life Cycle Assessment of Prestressed Concrete Railway Bridges in Himalayan Region of Jammu and Kashmir, India***" being submitted in the partial fulfillment of the requirement for the award of the degree of Doctor of Philosophy in ***Civil Engineering*** under ICFAI Tech School, The ICFAI University, Dehradun during the academic year 2023-24.

It is the work that is expected to be carried out under the supervision of ***Prof (Dr.) Ram Karan Singh***. It is further declared that the synopsis is within the plagiarism limit and copy of the same is attached as per the University norms.

Signature

Rajesh Kumar Singh

Enrollment ID: RSITS230027

Date: 06.01.2024

The ICFAI University, Dehradun

CERTIFICATE

This is to certify that the thesis entitled, ***"Life Cycle Assessment of Prestressed Concrete Railway Bridges in Himalayan Region of Jammu and Kashmir, India"*** is an original piece of work done by ***Rajesh Kumar Singh*** under my supervision being submitted in the partial fulfillment of the requirement for the award of the degree of Doctor of Philosophy in ***Civil Engineering*** under ICFAI Tech School, The ICFAI University, Dehradun during the academic year 2023-24.

Further, it is certified that the synopsis is within the plagiarism limit and copy of the same is attached as per the University norms.

Signature of the Supervisor in full

Name in Capital Letters DR. RAM KARAN SINGH

Designation & Address _____

_____

_____

Table of Contents

List of Tables

List of Figures

Abstract 7

1 Introduction 8

2 Research Problem 12

2.1 Sustainable Construction. 12

2.2 Data Collection Result and Discussion 13

2.2.1 Impact Assessment and Selection of Indicators 15

2.2.1.1 Economic Criteria 15

2.2.1.2 Environment Criteria 16

2.2.1.3 Social Criteria 21

3. Literature Review 26

4. Research Aim and Objectives 44

5. Significance of the Work 46

6. Month wise Plan of the Work 47

LIST OF TABLES

Table No.	Description	Page No.
1.4	Main Environmental criteria and indicator	*18*
1.5	Main Social; criteria and indicators	*22*

LIST OF FIGURES

Figure No.	*Description*	*Page No.*
1.1.	Sustainable Development model from Mebratu, 1998	*05*
1.2.	Relation between eco-design strategies and product life cycle	*08*
1.3.	Systematic Literature Review	*10*

ABSTRACT

Considering the significant impacts associated with constructing and maintenance of infrastructures considering the environmental, economic, and social dimensional aspects, adopting a sustainable design approach is deemed essential to facilitate the realization of the United Nations' Sustainable Development Goals. To address the intricate and often conflicting criteria inherent in sustainability, multi-criteria decision-making methods are commonly employed. This study aims to comprehensively examine the current state of applying these techniques in assessing the infrastructure sustainability, including an analysis of the sustainability impacts and criteria considered in these assessments.

The Analytic Hierarchy Process stands out as one of the most frequently utilized weighting techniques, while the Simple Additive Weighting method has emerged as the predominant decision-making approach for evaluating weighted criteria. Although life cycle assessment is regularly employed to assess sustainability, adherence to standardized concepts, such as cost discounting, or the explicit presentation of assumed functional units or system boundaries as required by ISO 14040, remains somewhat limited. Furthermore, there is an opportunity for additional research to explore the incorporation of fuzziness in handling linguistic variables in the assessment process.

Prestressed concrete bridges, integral components of infrastructure, are vulnerable to various courses of deterioration, including but not limited to formation of voids, corrosion, cracking, bond loss, fatigue, top layer reduction, delamination, and weakening strength and stiffness. Continuous assessment of their condition is needed to preemptively address potential issues. There are different methods to assess the remaining prestressing force, and no single nondestructive monitoring or inspection technique can give enough information. However, there are promising combinations of techniques that can be used.
Prestressed concrete bridges offer several advantages, including longer lengths, which increase unobstructed floor space and parking facilities. They also require less materials for construction with enhanced concrete finish, resist higher stresses, and Facilitate swift construction while enhancing quality control. Additionally, reduced maintenance is required and are more suitable for repetitive construction than regular concrete without prestressing.

However, there are also some disadvantages to consider such as High-strength concrete and steel wires with elevated tensile strength are essential for prestressed concrete., as well as specialized equipment like jacks and anchorage. It also demands skilled technology and highly skilled workers under skilled supervision. Furthermore, economical viability is restricted to large-span structures exclusively., requires ample space for precast works, and transportation of prestressed concrete can be difficult. Moreover, it requires the use of higher grades of concrete and steel to attain optimal strength.

In summary, while prestressed concrete bridges offer significant advantages such as longer spans and reduced maintenance, they also come with challenges related to construction, material requirements, and the need for specialized skills and equipment.

In this context, this study will focus primarily on the prestressed railway bridges in the Himalayan region, in view that the Himalayan conditions are very challenging not only for designers considering the terrain, but also to carry out execution of work in such volatile environment. The prestressed concrete are exposed to one of the harshest environment on the planet.

1. Introduction

The foundation for defining sustainable development is rooted in the report of the Brundtland Commission (WCED, 1987), which characterizes it as *"development that meets the needs of the present generation without compromising the needs of the future generation"*. The concept suggests the economic aspect, environmental aspect and social aspect, the three main components/pillars are considered. Therefore, attaining sustainable development signifies a convergence of these three primary aspects, each typically pursuing distinct targets or goals.

The figure indicated below, labeled as Figure 1.1, illustrates the three intersecting domains encompassing economic, social, and environmental elements (Mebratu, 1998). This representation signifies that sustainable development is reliant on the three pillars of the Triple Bottom Line (TBL) approach.

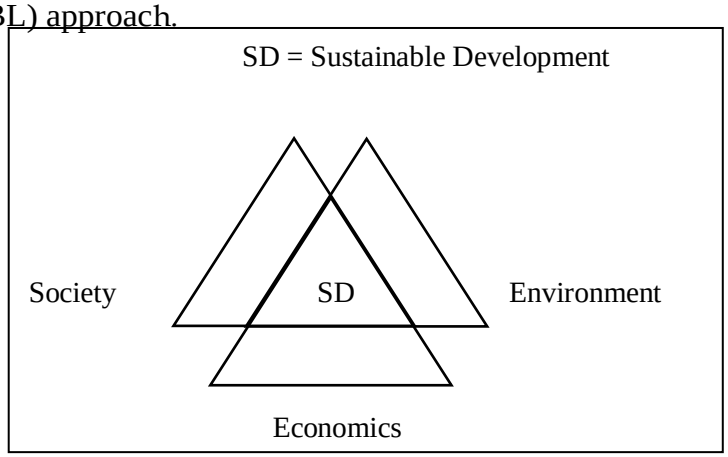

Fig 1.1 – Sustainable Development model from Mebratu, 1998

The construction industry stands out as one of the most dynamic sectors, wielding substantial influence over global economic, environmental, and social dimensions. This underscores the imperative for a shift towards the sustainability of buildings and structures. Construction of bridges counts its own importance. It not only connects two land masses but also flaunts engineering/architectural skillset. The construction and upkeep of bridges play a pivotal role, not just in addressing connectivity challenges but also in fostering optimal transportation between diverse locations. Consequently, assessing sustainable development throughout the entire life cycle becomes imperative. Among the three primary components of sustainable development, the social aspect has received comparatively less attention, with limited knowledge available on its assessment. Conversely, studies on the economic and environmental facets have been conducted more extensively, leading to the assumption that their consideration is adequate.

Furthermore, during recent times, the infrastructure industry has emerged as a significant environmental stressor, accounting for around 30% consumption of global energy, 30% emission of greenhouse gas , and 40% extraction of raw material (Choi, 2019). Projections indicate that by 2030 ,world's cement production rate will be approximately 1.4 times more than as compared to 2013 (Imbabi et al., 2013).

Conversely, In countries infrastructure is acknowledged as a primary driver/factor of economic well-being and social development in countries, facilitating the provision of services and territorial organization. According to estimates from the International Monetary Fund, investing an additional 1% of Gross Domestic Product (GDP) in infrastructure can lead to an average 1.5% increase in the world's GDP within four years. This aligns with the observation that around 20% of recent World Bank loans have been allocated to transport infrastructure (Kyriacou et al., 2019).

Furthermore, the construction sector contributes approximately 9% to Europe's GDP and sustains 18 million direct jobs (Favier et al., 2018).

Driven by concerns about the construction sector's economic, environmental, and social footprint, sustainability in infrastructure development has risen to prominence. Recognizing this urgency, the United Nations established SDG 9 in 2015, emphasizing the immediate need for reliable, sustainable, and resilient infrastructure by 2030. Research by NCE (2016) further highlights the positive ripple effects of sustainable infrastructure design, linking it to the achievement of multiple SDGs. From fostering economic growth and reducing inequalities to promoting responsible consumption and building sustainable cities, the benefits are clear. Moreover, sustainable infrastructure plays a crucial role in combating climate change and protecting biodiversity, directly contributing to SDGs 13 and 15. In conclusion, NCE (2016) aptly states that investing in sustainable infrastructure is a critical leap towards meeting global challenges and securing a sustainable future for all.

Given the circumstances, particular attention is needed for infrastructures exposed to extreme environmental conditions that may accelerate degrading processes, compromising their functionality for full potential and leading to substantial maintenance demands throughout their service lives. As concrete stands as the world's most utilized construction material and the second most consumed substance globally, following water, managing the degradation of concrete structures poses one of the most challenging issues in recent times for the construction industry (Gjørv, 2013).
In Europe alone, annually the costs incurred on repair activities on concrete structures exceed €15 billion, which is more than 50% of the continent's annual construction budget (Zewdu et al., 2013). The impacts stemming from the maintenance of concrete structures become particularly significant when dealing with those exposed to hilly environments, where excessive rainfall is acknowledged as the critical threat to concretes. As per the report issued by NACE (2016), the direct costs associated with corrosion is estimated to be around 3.4% of the world's GDP. As per this report, it is anticipated that economic savings ranging between 15% and 35% of the yearly losses due to the impact of corrosion implementing effective corrosion control practices.
It is essential to emphasize here that the above mentioned need of maintenance associated with corrosion leads to a considerable environmental emission due to the resulting increase in demands for concrete and cement production. The production of cement for concrete alone contributes to approximately 8% of the global annual carbon dioxide emissions (Olivier et al., 2016). In Europe, around 20% of the cement produced is consumed in maintenance and works of rehabilitation activities (Favier et al., 2018). In Western Europe, rate of cement consumption related to rehabilitation works have increased from 34% of the total cement consumption in construction activities in 2007 to around 44% in 2017.
Taking into account the social, economic, and environmental significance of the construction sector and considering the relevant proportion of these impacts resulting from problem of corrosion , it is evident that the 2030 Agenda needs to address the extent to which the consideration of sustainability criteria may influence the choice of design for structures in the hostile environment of the Himalayan region.

Sustainable design necessitates the consideration of economic, environmental, and social aspects. However, it is commonly observed that present day sustainability assessments of infrastructures predominantly focus on economic and environmental perspectives only, with minimum/less attention given to the social dimension (Diaz-Sarachaga et al., 2016). The comprehensive approach required for any such sustainability assessment is impeded by a significant knowledge gap concerning the evaluation of impact on society throughout the life cycle of product (Jorgensen,

2013). While the environmental life cycle assessment (LCA) methodology has become well-established both methodologically (ISO, 2006a) as well as in practical implementation (ISO, 2006b), social life cycle assessment (SLCA) is a relatively new area of research and it requires additional consistent development efforts (Sierra et al., 2018a).

Assessing social life cycle impacts in context of sustainability is a complex and subjective task. The UN Environmental Program has recently developed guidelines for consistent SLCA of products (UNEP/SETAC, 2009) as an initial attempt to lay the groundwork for a future standardized methodology based on the ISO 14040 series for social assessments.

Despite these efforts, significant discrepancies in both the definition of social criteria and the application of evaluation techniques for SLCA highlight the need for greater emphasis on constructing coherent methodologies consistent with accepted LCA standards. Consequently, a consistent and universally accepted methodology for evaluating the sustainability of products from a holistic perspective is still lacking. Despite the existence of tools and standards guiding the life cycle assessment of products (ISO, 2006a, 2006b; UNEP/SETAC, 2009, 2013), a consensus is yet to be reached on their proper integration with the sustainability assessment of infrastructures throughout their life cycle.

The concept of sustainability was pioneered in the late 1970s. Following the Second World War, the expansive growth of industrial society led to a growing awareness of environmental impacts. This prompted the recognition of the necessity to devise means and tools to mitigate the escalating damage. In Goodland's words, "the need for sustainability arises from the recognition that the profligate, extravagant, and inequitable nature of current patterns of development, when projected into the not-too-distant future, lead to biophysical impossibilities" (Goodland, 1995). In 1987, with the Brundtland Commission report "Our common future", when the idea of sustainability was ultimately embraced.

In 1992, during the Rio de Janeiro Conference, the United Nations Environmental Program officially embraced sustainability as the primary objective for the future development of our society. It was established as the central task for the 21st century (UNEP, 1992). In 2002, the World Summit on Sustainable Development convened in Johannesburg, bringing together government and business leaders to discuss recent advancements and lay the groundwork for a collective strategy to address the challenges of sustainable development. Key objectives included fostering a shift towards more sustainable production and consumption practices and mitigating impacts on human health and the environment through a life cycle approach. The foundational principles for this sustainable development encompassed economic growth, ecological balance, and social progress (WBCSD, 2003). A pivotal moment for sustainability occurred in 1997 with the adoption of the Kyoto Protocol, establishing the framework for reducing greenhouse gas emissions in the context of sustainable development.

Quoted from Brundtland Report in 1987, *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*

The commitment to achieving sustainable development across all sectors of society necessitates the integration of this mindset into every stage of a project's lifecycle, particularly during the design phase. Effective design and planning have the potential to result in an environmentally friendly project, thereby reducing energy and resource consumption. This presents a significant challenge for today's engineers, who bear the responsibility of steering progress towards a sustainable world. Eco-design, a relatively recent concept, entails techniques for structured product development, emphasizing the need for environmental management and control policies within

companies and organizations.
Eco-design involves a comprehensive examination of the entire life cycle of existing products to identify critical performance aspects for improvement. Similarly, it addresses products in the early stages of development to proactively minimize future environmental and socio-economic costs. To pinpoint these critical stages in a product's life that require enhancement, methodologies like Life Cycle Assessment have proven to be invaluable. Whether for environmental, economic (White et al., 1996; Norris, 2001), or social (O'Brian M. et al., 1996; Norris et al., 2005) considerations, any assessment method must encompass the entire life cycle of the studied system. The Life Cycle approach has emerged as fundamental for sustainable design.

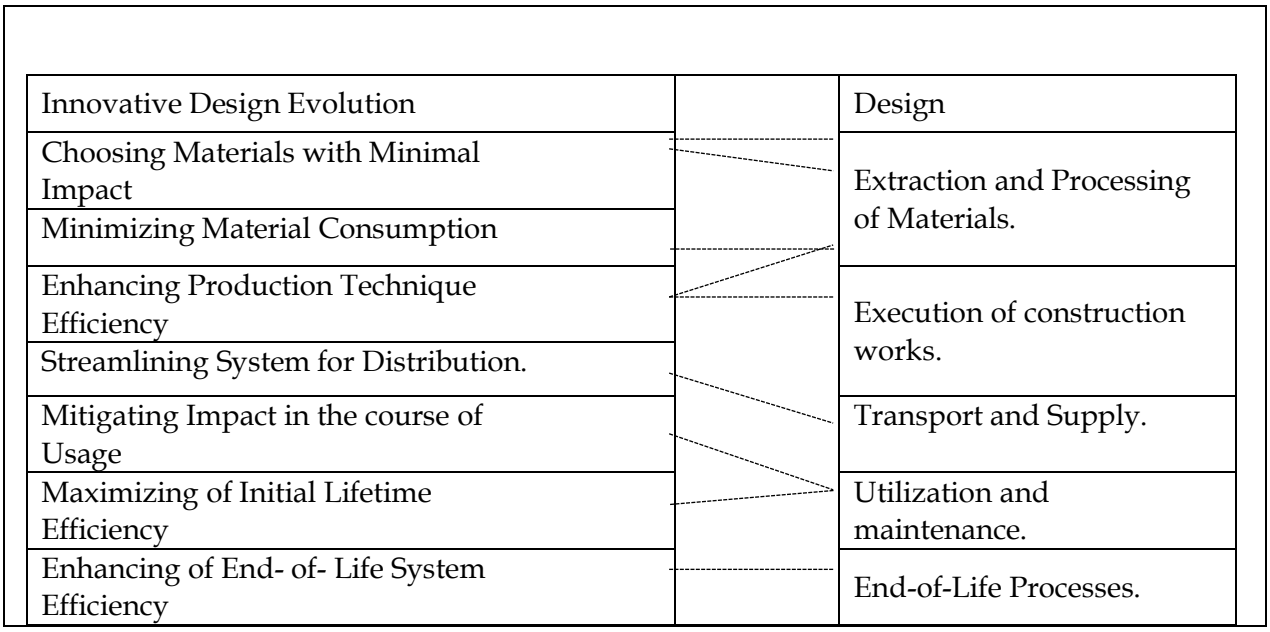
Innovative Design Evolution
Design
Choosing Materials with Minimal Impact
Minimizing Material Consumption
Extraction and Processing of Materials.
Enhancing Production Technique Efficiency
Streamlining System for Distribution.
Execution of construction works.
Mitigating Impact in the course of Usage
Transport and Supply.
Maximizing of Initial Lifetime Efficiency
Utilization and maintenance.
Enhancing of End- of- Life System Efficiency
End-of-Life Processes.

Fig 1.2 – Relation between eco-design strategies and product life cycle

By implementing effective environmental management, companies can not only realize tangible benefits such as a reduction in energy and resource consumption and decreased environmental fines but also leverage positive eco-friendly marketing. In a society increasingly focused on environmental issues, a robust environmental management system becomes a pivotal element in corporate strategies, establishing the groundwork for competitive growth where a better and sustainable future is the primary objective (Hart, 1997).

While sustainable development necessitates the involvement of all sectors of society, engineers play a crucial role in this transformative process. As primary stakeholders, engineers must recognize their responsibilities and integrate these environmental principles into enhanced designs for their projects.

2. Research Problem

2.1 Sustainable Construction

The construction sector stands out as a major contributor to overall resource and energy consumption, waste generation, and greenhouse gas emissions in Europe. The concept of sustainable construction holds particular significance for engineers and developers, tasked with crafting new environmentally conscious structures while addressing the aforementioned aspects. To realize this objective, sustainable construction is embedded in European policy, supported by numerous standards and regulations that govern and evaluate processes and materials within the building sector.
Sustainable construction transcends merely designing and erecting new buildings and infrastructure with commendable environmental performance. It also entails scrutinizing existing structures to pinpoint areas requiring modifications to align with sustainable objectives. In evaluating these pre-existing constructions, engineers should explore the utilization of eco-friendlier materials or processes, aiming to mitigate the impact of demolition or waste disposal. Equally important is the creation of structures demanding fewer maintenance operations throughout their lifespan, thereby curbing energy and resource consumption. This approach also serves to prolong the service life, minimizing the need for premature replacement of entire structures.

In recent years, the construction industry has emerged as a prominent environmental stressor in our society, accounting for 30% of global energy consumption, 40% of raw material extraction, and 30% of greenhouse gas emissions (Choi, 2019). Notably, the production of cement for concrete alone contributes approximately 8% of the world's annual CO2 emissions (Olivier et al., 2016). Conversely, investments in public capital, such as infrastructure projects, play a crucial role in fostering economic well-being and social development. These projects contribute to regional connectivity and the provision of essential services, with around 20% of recent World Bank loans allocated to transport infrastructure (Kyriacou et al., 2019).

Recognizing the profound implications of infrastructure design, especially as these structures often serve broad segments of society across generations, researchers have increasingly focused on assessing various dimensions of sustainability related to infrastructure design. Studies have explored cost optimization in both infrastructure design (Garcia-Segura et al., 2014a; Yepes et al., 2017) and maintenance (Frangopol, 2011; Safi et al., 2015). Environmental impacts throughout the life cycle of structures, from bridges (Navarro et al., 2018c; Zhang et al., 2016; García-Segura et al., 2018) to buildings (Van den Heede & De Belie, 2014), as well as specific construction processes like concrete production (Braga et al., 2017), have been subjects of investigation. Social impacts associated with the use of various building materials for construction (Hossain et al., 2018) and for road infrastructure projects (Sierra et al., 2018b) have also been scrutinized in recent years. Despite the existence of standardized tools for assessing the life cycle impacts of products, there is currently no consensus on an objective and universal methodology for evaluating the sustainability of a particular infrastructure design. The lack of agreement extends to how to simultaneously consider the three pillars defining sustainability or which specific criteria should guide the decision-making process in sustainable infrastructure design (Montalban-Domingo et al., 2018).

To deal with the assessment of the conflicting dimensions of sustainability in a multi- stakeholder and long-term context like infrastructure design, the use of multi-criteria decision-making (MCDM) techniques has revealed itself as the most suitable approach compared to other methods commonly used in infrastructure design, such as single-or multi-objective
optimization. MCDM techniques allow the decision maker to assess complex problems involving

multiple and divergent criteria on the basis of the subjective judgments of a panel of experts or of stakeholders affected by the decision. Therefore, this paper is devoted to analyse the current trends regarding the application of MCDM techniques to the sustainability assessment of infrastructure design, paying special attention to the particular criteria considered in these assessments.

2.2 Data Collection, Results and Discussion

The course of collection of data in this literature review comprises twofold, as illustrated in the figure below. The initial stage aims to establish a preliminary set of contributors, laying the groundwork for constructing a final set by subsequent filteration and expansion process in Stage two.

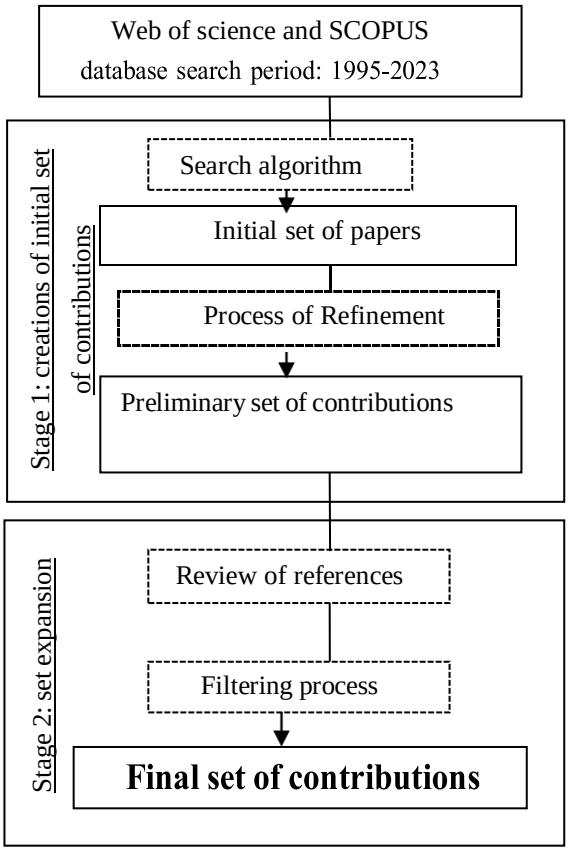

Fig 1.3 – Model for review of literature.

The exploration is conducted using scientific bibliographic databases such as SCOPUS, Web of Science, and others. The search timeframe spans from 1995 to 2023, as no pertinent contributions have been identified prior to this period. The search algorithm employed to identify articles forming the initial set involves a combination of terms like “Multi criteria decision making”, “MCDM and “Sustainability” along with other civil engineering-related terms, such as “Construction” or Infrastructure”. This is achieved using Boolean operators like "AND" and "OR."

To refine the results thus obtained, several exclusion criteria were applied to establish the initial set of papers. Initially, only original, peer-reviewed scientific articles and conference proceedings were considered. Additionally, manuscripts lacking clear identification of the MCDM technique used or the sustainability criteria considered were not considered. Furthermore, articles were required to assess at least two of the three sustainability dimensions through a judicious selection of decision criteria. Lastly, only those articles were included in this study which are written in English in this study.

After generating the initial set of contributions, the relecferences cited in the selected manuscripts were scrutinized. The set was then expanded by applying the aforementioned filtering process to articles referenced in the papers included in the initial set, resulting in the final expanded set of manuscripts. This sampling technique has been utilized in previous literature review works (Sierra et al., 2018; Zamarron-Mieza et al., 2017). In this case, the expanded final set comprises 83 contributions.

Nevertheless, there was an initial significant increase in the number of publications addressing the sustainability assessment of infrastructures in 2007, with a substantial surge observed in 2015 (as illustrated in the figure below). More than half of the publications utilizing MCDM techniques for sustainable infrastructure design emerged after 2015, marking a notable shift compared to the preceding decades (i.e., 1996 to 2014). This surge can be attributed to the establishment of the Sustainable Development Goals by the United Nations General Assembly in 2015. Among the 17 Goals outlined, some are directly related to sustainable economic growth, decent work, resilient and sustainable infrastructures, and climate action. This elucidates the significant efforts exerted by the scientific and research community since 2015 for facilitating the sustainable design of infrastructures.

As suggested by information the data gathered after study of publication from 1996 to 2023, the MCDM techniques can be broadly applied in 6 main categories which are as follows:

1. **Buildings:** With 38.6% (32 publications), MCDM techniques have been widely applied for assessment of aspects of sustainability for design of buildings. Authors have primarily emphasised either on assessment of designs of particular structural elements of buildings such as columns (Pons & De la Fuente, 2013), slabs (Blanco et al., 2016; Reza et al., 2011), and beams (Mosalam et al., 2018), or the research on assessment of sustainable design of building envelops namely Guzmán-Sánchez et al., 2018; Hashemkhani et al., 2018; Invidiata et al., 2018; Kamali et al., 2018; Moussavi et al., 2017; Gilani et al., 2017; Jalaei et al., 2015; Perini & Rosasco, 2013; Saparauskas et al., 2010 along with comparison of different construction materials by Motuziene et al. & Nassar et al., Samani et al. (2015), Akadiri et al. (2013), and Pons and Aguado (2012). Moreover, apart from that some publication have also been made for development of the indicators suitable for measuring the sustainability of buildings such as Mahdiraji et al., 2018; Ignatius et al., 2016; Drejeris & Kavolynas, 2014; Yu et al., 2012; Alwaer & Clemens-Croome, 2010. Special emphasis is given to the sustainable planning of industrial structures. by Heravi et al., 2017; Cuadrado et al., 2016; Cuadrado et al., 2015; Lomber & Aprea, 2010.
   Formisano and Mazzolani (2015), as well as Terracciano et al. (2015), aim to assess sustainability of various options for energy retrofitting of buildings in regions with high seismic activity. Additionally, other objectives are addressed, including restoration alternatives for abandoned buildings (Zavadskas et al., 2010, 2007), and optimal building placement (Hosseini et al., 2016).
2. **Bridges:** Thirteen papers, accounting for 15.7% of the examined manuscripts, focus on the sustainability assessment of bridges. Assessment is mainly categorized on sustainability of bridge deck designs (Kripka et al., 2019; Yepes et al., 2015a; Jakiel & Fabianowsky, 2015; Balali et al., 2014; Gervásio & Da Silva, 2012; Farkas, 2011; Malekly et al., 2010).
3. **Energy Infrastructures:** Twelve papers, constituting 14.5% of the overall publications, delve into the sustainability of various aspects of energy infrastructure. These topics include the evaluation of the most sustainable energy production systems (Montajabiha, 2016; Väisänen et al., 2016; Barros et al., 2015; Klein & Whalley, 2015; Barros et al., 2015; Kaya & Kahraman, 2010; Jovanovic et al., 2009; Begic & Afgan, 2007). Conversely,

discussions have revolved around the optimal siting of energy production plants and the evaluation of sustainability performance for various designs of wind turbines and towers by González et al., 2018; Fetanat & Khorasaninejad, 2015 and De la Fuente et al., 2017a; Pons et al., 2017; Gumus et al., 2016 respectively.

4. **Hydraulic Infrastructure:** A total of 13.3% of the publications elucidate the sustainability aspects of diverse hydraulic infrastructures, including dams (Sun et al., 2013; Afshar et al., 2011; Gento, 2004), urban drainage (Tahmasebi & Yazdandoost, 2018; Dong et al., 2008; Martin et al., 2007), sewerage systems (De la Fuente et al., 2016b), and water supply systems (Pascal et al., 2017; Chhipi-Shrestha et al., 2017; Abrishamchi et al., 2005; Jaber & Mohsen, 2001).
5. **Transport Infrastructure:** A portion of 7.2% of the research literature focuses on elements and concepts associated with the transport system, addressing aspects such as the sustainable design of road pavements (Santos et al., 2019; Torres-Machí et al., 2015; Kucukvar et al., 2014; Jato-Espino et al., 2014). This includes topics like the optimal selection of road locations (Hashemkhani et al., 2011) and the creation of assessment tools for evaluating transport projects (Oses et al., 2017).
6. **Others:** The remaining 10.7% of papers encompass a range of topics covering various aspects of sustainable design. These include assessments for tunnel projects (De la Fuente et al., 2017b & 2016a), ports (Asgari et al., 2015), the location of demolition waste facilities (Banias et al., 2010), the selection of coating materials for construction (Rochikashvili & Bongaerts, 2016), and the development of assessment tools for evaluating construction projects in general terms. (Dobrovolskiiene & Tamosiuniene, 2016; Reyes et al., 2014; Saparauskas, 2007; Ugwu & Haupt, 2007).

2.2.1 Impact Assessment and Selection of Indicators:

Sustainable life cycle assessments rely on evaluating the impacts generated by various activities considered in the analysis. Therefore, it is crucial to specify not only the impacts (criteria) to be included in the analysis early in the decision-making process but also the methods used to assess these impacts. Among the examined publications, 74.7% (62 papers) base their assessments on impacts from at least two different stages of the infrastructure's life cycle. A standardized methodology in the environmental field (ISO, 2006a, 2006b) is employed to evaluate life cycle impacts and establish consistent impact categories, ensuring a rigorous assessment of alternative options. Although there is no ISO standard for the economic field, life cycle costing has reached an advanced stage of development (Hunkeler et al., 2008). However, the evaluation of the social dimension of sustainability is still in the research and development phase. In 2009, an attempt was made to establish an objective methodology for identifying and assessing social impacts through the 'Guidelines for social life cycle assessment of products' (UNEP/SETAC, 2009), guided by the ISO-standardized methodology for environmental impact assessments. Despite these efforts, only 4 out of the 83 reviewed papers (4.8%) adhere to the ISO methodology, explicitly defining a suitable functional unit and the assumed system boundaries in the assessment (Vaisanen et al., 2016; Motuziene et al., 2016; Samani et al., 2015; Reza et al., 2011). While not strictly following the ISO methodology, other authors do explicitly define the functional unit and system boundaries (Invidiata et al., 2018; De la Fuente et al., 2017b, 2016a, 2016b; Kucukvar et al., 2014).

2.2.1.1 Economic Criteria

Only 7 Out of the 83 reviewed manuscripts do not consider economic criteria in their sustainability assessments. In rest 76, three main economic impacts have been identified,

namely the construction or implementation costs, the costs derived from maintenance and operation of the infrastructure, and the costs resulting from the end of life stage. 94.7% of the reviewed papers that take into account the economic dimension of sustainability assumes the costs derived from the installation of the infrastructure relevant in the assessment. Only 13.3% of the reviewed papers consider the direct costs associated with the disposal of the infrastructure in their assessments, and 63.9% the costs of the maintenance and operation life cycle stage.

It is to be noted that, among the papers reviewed, only 5 explicitly present the assumed discount rates that allow to transform future costs into present currency values. In the case of building design, Mosalam et al. (2018) consider a discount rate of 3%, Jalei et al. (2015) assume a discount rate of 5%, and Perini and Rosasco (2013) evaluates three different economic scenarios, with discount rates that range from 4.5% to 5.5%. Torres- Machi et al. (2015), when assessing the sustainability of road pavement treatments, assume a discount rate of 5%. Klein and Whalley (2015) evaluate a cost discounting range that varies from 3% up to 10%.

2.2.1.2 Environmental Criteria

Referring aspects of sustainability with respect to the environmental dimensions, studies are widely reviewed and discussed which further can be fractionated between 7 main impact categories namely emissions of pollutants, energy consumptions, raw material (resource) consumptions, waste generations, land use, eutrophication, and ozone layer depletion. Below mentioned table may be referred to assess the category wise references:

Environmental Criteria	Indicator	Type of Assessment	References
(i) Emission of pollutants	Kg CO2/Output unit	Quantitative	Santos et al. (2019) Guzmán-Sánchez et al. (2018) Invidiata et al. (2018) Medina-González et al. (2018) Oses et al. (2017) Gilani et al. (2017) Moussavi et al. (2017) Pons et al. (2017) De la Fuente et al. (2017a, 2017b,2016a & 2016b) Motuziene et al. (2016) Nassar et al. (2016) Väisänen et al. (2016) Blanco et al. (2016) Torres-Machí et al. (2015)Klein & Whalley (2015) Barros et al. (2015) Samani et al. (2015) Yepes et al. (2015) Kucukvar et al. (2014) Jato-Espino et al. (2014) Pons & De la Fuente (2013) Pons & Aguado (2012) Reza et al. (2011) Jovanovic et al. (2009) Begic & Afgan (2007)
	Kg SO2/Output unit	Quantitative	Medina-González et al. (2018) Oses et al. (2017) Väisänen et al. (2016) Klein & Whalley (2015)Barros et al. (2015) Samani et al. (2015) Reza et al. (2011) Begic & Afgan (2007)

	Kg NOx/Output unit	Quantitative	Medina-González et al. (2018) Oses et al. (2017) Väisänen et al. (2016) Klein & Whalley (2015) Barros et al. (2015) Samani et al. (2015) Reza et al. (2011) Jovanovic et al. (2009) Begic & Afgan (2007)
	€/kg pollutant removed	Quantitative	Perini & Rosasco (2013)
	Costs of medical care needs due to pollution (€)	Quantitative	Mikawi (1996)
	Oxygen, Nitrogen and Phosphates emitted to water	Quantitative	Dong et al. (2008)
	Assessment by experts through point scale	Qualitative	Hashemkhani et al. (2018) Kamali et al. (2018) Mahdiraji et al. (2018) Tahmasebi & Yazdandoost (2018) Pascal et al.(2017) Heravi et al. (2017) Rashidi et al. (2017 & 2016) Montajabiha (2016) Gumus et al. (2016) Rochikashvili & Bongaerts (2016) Dobrovolskiiene & Tamosiuniene (2016)Jalaei et al. (2015) Cuadrado et al.(2015) Jakiel & Fabianowski (2015) Fetanat & Khorasaninejad (2015)Asgari et al. (2015) Drejeris & Kavolynas (2014) Balali et al. (2014) Chen (2014) Reyes et al. (2014)Sun et al. (2013) Akadiri et al. (2013) Yu et al. (2012) Farkas (2011) Hashemkhani et al. (2011), Kaya & Kahraman (2010) Saparauskas et al. (2010) Wang et al. (2008) Dabous & Alkass (2008) Ugwu & Haupt (2007) Jaber & Mohsen (2001)

(ii) Energy Consumption	MJ (MWh)/output unit	Quantitative	Santos et al. (2019) Guzmán-Sánchez et al. (2018) Invidiata et al. (2018) Medina-González et al. (2018) Gilani et al. (2017) Moussavi et al. (2017) De la Fuente et al. (2017a, 2017b & 2016a) De la Fuente et al. (2016b), Nassar et al. (2016) Blanco et al. (2016) Motuziene et al. (2016) Samani et al. (2015) Kucukvar et al. (2014) Jato-Espino et al. (2014) Pons & Aguado (2012) Reza et al. (2011) Gento (2004)
	Assessment by experts through point scale	Qualitative	Hashemkhani et al. (2018) Kamali et al. (2018) Heravi et al. (2017) Ignatius et al. (2016) Dobrovolskiiene & Tamosiuniene (2016)Gumus et al. (2016) Asgari et al.(2015), Jalaei et al. (2015) Drejeris & Kavolynas (2014) Akadiri et al. (2013), Yu et al. (2012) Lombera & Aprea (2010)
(iii) Raw material consumption (Resource Depletion)	Consumption/output unit	Quantitative	Santos et al. (2019), Medina-González et al. (2018) Guzmán-Sánchez et al. (2018) Gilani et al. (2017) Moussavi et al. (2017) De la Fuente et al. (2017a, 2017b, 2016a) Blanco et al. (2016) Samani et al. (2015) Klein & Whalley (2015) Jato-Espino et al. (2014) Kucukvar et al. (2014) Pons & De la Fuente (2013) Reza et al. (2011) Gento (2004)
	Asessment by experts through point scale	Qualitative	Kamali et al. (2018) Heravi et al. (2017) De la Fuente et al. (2016b) Ignatius et al. (2016) Cuadrado et al. (2015) Jalaei et al. (2015) Drejeris & Kavolynas (2014) Akadiri et al. (2013) Yu et al. (2012) Lombera & Aprea (2010) Banias et al. (2010) Ugwu & Haupt (2007)

(iv) Waste generation	kg/output unit	Quantitative	Medina-González et al. (2018) Gilani et al. (2017) Samani et al. (2015) Kucukvar et al. (2014) Pons & Aguado (2012)
	Assessment by experts through point scale	Qualitative	Hashemkhani et al. (2018) Kamali et al. (2018) Heravi et al. (2017) Cuadrado et al. (2015) Asgari et al. (2015) Drejeris & Kavolynas (2014) Reyes et al. (2014) Akadiri et al. (2013) Yu et al. (2012) Lombera & Aprea (2010) Banias et al. (2010) Ugwu & Haupt (2007)
(v) Land use	m2/output unit	Qualitative	Klein & Whalley (2015
	Asessment by experts through point scale	Qualitative	Guzman-Sanchez et al. (2018) Hashemkhani et al. (2018) Heravi et al. (2017) Gumus et al. (2016) Montajabiha (2016) Fetanat & Khorasaninejad (2015) Jakiel & Fabianowski (2015) Drejeris & Kavolynas (2014) Perini & Rosasco (2013) Sun et al. (2013) Yu et al. (2012) Afshar et al. (2011) Hashemkhani et al. (2011) Lombera & Aprea (2010) Banias et al. (2010) Kaya & Kahraman (2010) Malekly et al. (2010) Ugwu & Haupt (2007)
	Aquatic ecotoxicity, salinity, biological indices	Quantitative	Vaisanen et al. (2016) Dong et al. (2008) Martin et al. (2007)
(v) Eutrophication	kg Phosphate/output unit	Quantitative	Santos et al. (2019) Medina-González et al. (2018), Väisänen et al. (2016) Nassar et al. (2016) Samani et al. (2015)
	Asessment by experts through point scale	Qualitative	Sun et al. (2013) Afshar et al. (2011) Lombera & Aprea (2010) Ugwu & Haupt (2007)

(vi) Ozone depletion	kg CFC (Chlorofluorocarbons) / output unit	Quantitative	Santos et al. (2019) Medina-González et al. (2018) Motuziene et al. (2016 Nassar et al. (2016) Väisänen et al. (2016) Samani et al. (2015)
	Assessment by experts through point scale	Qualitative	Akadiri et al. (2013) Lombera & Aprea (2010)

Table –1.4 – Major Environmental indicators and criteria

Emission of pollutants is the most discussed criteria within the reviewed papers as an indicator of the environmental impact of an infrastructure. It not only takes into account emissions resulting from the production of construction materials and works but also considers externalities associated with infrastructure construction and maintenance, such as traffic congestion (Mikawi, 1996). Some authors have specifically focused their studies on air pollutants like carbon dioxide (Kripka et al., 2019; Invidiata et al., 2018; Moussavi et al., 2017; De la Fuente et al., 2016a; Perini & Rosasco, 2013), SO2, or NOx (Vaisanen et al., 2016; Begic & Afgan, 2007), and general greenhouse gases (Kamali et al., 2018; Gumus et al., 2016). Others have also paid attention to pollutants released into water (Dong et al., 2008; Tahmasebi & Yazdandoost, 2018; Martin et al., 2007) in the context of urban water systems.

Energy consumption is an another considerable criteria within the reviewed papers, approximately 46.3% of the articles identifying it as supplementary measures for assessing the environmental impact of infrastructure. The majority of the articles focus on the energy required for producing construction materials and constructing the specific infrastructure under evaluation (Kamali et al., 2018; Pons et al., 2017; Motuziene et al., 2016), while certain authors also take into account energy savings resulting from building envelope designs (Perini & Rosasco, 2013).

Moreover, the depletion of natural resources is considered a primary consequence of unsustainable construction practices. Thirty-two studies assess the consumption of natural resources in their sustainability evaluations, specifically focusing on construction materials. Some authors have had also considered the positive environmental impact due to the use of recycled materials (Guzman-Sanchez et al., 2018; Jalaei et al., 2015; Jato-Espino et al., 2014) or using potentially reusable materials (Santos et al., 2019; Gilani et al., 2017; Nassar et al., 2016; Akadiri et al., 2013)

Recognizing the construction industry as one of the leading contributors to global waste production (Marzourk & Azab, 2014), initiatives have been undertaken to address its detrimental impact in environmental assessments. About 25.3% of the scrutinized manuscripts incorporate the assessment of waste generation arising from industrial processes in the production of construction materials or from demolition activities. This consideration encompasses both solid waste from construction materials (Mosalam et al., 2018; Gilani et al., 2017) and water waste (Chhipi-Shrestha et al., 2017).

Use of Land is an environmental concept that implies both land occupation and transformation of land. Land used in the construction of infrastructures results in damage to ecosystems and loss of biodiversity. From the 83 reviewed articles, 25 (30.1%) take land use into account as an indicator of the environmental damage derived from infrastructures. The effects of land use have been accounted for as local ecosystem disturbances (Banias et al., 2010), destruction of wildlife habitats (Heravi et al., 2017; Hashemkhani et al., 2011), proximity to migratory paths (Fetanat & Khorasaninejad, 2015), effects on biodiversity (Guzman-Sanchez et al., 2018; Vaisanen et al., 2016).
Given the particular scope of their study, Perini and Rosasco (2013) considered the creation of habitats.

Approximately 10.8% described in 9 articles explains emission of pollutants, predominantly phosphates derived from human activities to water causes eutrophication which encourages an uncontrolled growth of algae eventually endangering the survival of other water species and water body as a whole. Dying of lakes is one of the activity seems common due to eutrophication.

Ozone is a gas present in the lower level of stratosphere. It is a formed by covalent bond between three oxygen atom. It makes a protective layer in the atmosphere which acts as a cover to the Earth against ultraviolet radiation of the Sun. The ozone layer is present in variable extent less dense near the surface of the Earth compared to the height of 30 km. The depletion of Ozone layer is because of the emission of substances containing chlorine and bromine atoms has been accounted in eight studies as an additional indicator capable of assessing and measuring the extent of environmental damage due to infrastructures and their associated activities.

2.2.1.3 Social Criteria

The criteria assessed in the studies exploring the social dimension of sustainabilitycan be categorized in eight major indicators which are mentioned along with reference details in the below mentioned table:

Social Criteria	Indicator	Type of Assessment	References
(vi) Social wellbeing	Increase of income of local population (€/year)	Quantitative	Zavadskas & Antucheviciene (2010, 2007)
	Assessment by experts through point scale	Qualitative	Guzmán-Sánchez et al. (2018) Hashemkhani et al. (2018) Kamali et al. (2018) Mahdiraji et al. (2018) Tahmasebi & Yazdandoost (2018)Heravi et al. (2017) Dobrovolskiiene & Tamosiuniene (2016)Gumus et al. (2016) Ignatius et al. (2016) Montajabiha (2016) Nassar et al. (2016)

			Fetanat & Khorasaninejad (2015) Jalaei et al. (2015) Drejeris & Kavolynas (2014) Jato-Espino et al. (2014) Afshar et al. (2011) Sun et al. (2013) Hashemkhani et al. (2011) Kaya & Kahraman (2010) Ugwu & Haupt (2007)
	Habitability Increase (m2)	Quantitative	Pons & De la Fuente (2013)
	Comfort (hours/year)	Quantitative	Invidiata et al. (2018)
(vii)	Aesthetics Assessment by experts through point scale	Qualitative	Kamali et al. (2018) Tahmasebi & Yazdandoost (2018) Moussavi et al. (2017) Rashidi et al. (2017) Ignatius et al. (2016) Rochikashvili & Bongaerts (2016) Barros et al. (2015) Cuadrado et al. (2015) Jalaei et al. (2015) Fetanat & Khorasaninejad (2015) Jakiel & Fabianowski (2015) Balali et al. (2014) Chen (2014) Jato-Espino et al. (2014) Akadiri et al. (2013) Perini & Rosasco (2013) Yu et al. (2012) Farkas (2011) Afshar et al. (2011) Banias et al. (2010) Lombera & Aprea (2010) Malekly et al. (2010) Saparauskas et al. (2010) Wang et al. (2008) Ugwu & Haupt (2007) Gento (2004)
(viii) work/output	Job creations Hours of unit	Quantitative	Väisänen et al. (2016) Klein & Whalley (2015) Kucukvar et al. (2014) Jovanovic et al. (2009) Begic & Afgan (2007)
	Gross Value Added/hour Worked	Quantitative	Saparauskas (2007)
	Unemployment rate	Quantitative	Banias et al. (2010)
	Employment increase (%)	Quantitative	Zavadskas & Antucheviciene (2010, 2007)
	Assessment by experts through point scale	Qualitative	Heravi et al. (2017) Gumus et al. (2016) Montajabiha (2016) Afshar et al. (2011) Kaya & Kahraman (2010)

(ix) Development of Local economies	GDP increase (€)	Quantitative	Zavadskas & Antucheviciene (2010, 2007) Saparauskas (2007)
	Land value degradation (€/m2)	Quantitative	Banias et al. (2010)
	Assessment by experts through point scale	Qualitative	Kamali et al. (2018) Heravi et al. (2017) Gumus et al. (2016) Barros et al. (2015) Fetanat & Khorasaninejad (2015)Akadiri et al. (2013) Sun et al. (2013) Afshar et al. (2011) Ugwu & Haupt (2007)
(x) Externalities	Noise pollution (dB)	Quantitative	Santos et al. (2019) Oses et al. (2017) De la Fuente et al. (2017b) Blanco et al. (2016) De la Fuente et al. (2016a)Banias et al. (2010)
	Traffic congestion (travel time)	Quantitative	Santos et al. (2019)
	Vehicle opertaing costs (€), User delay costs (€)	Quantitative	Gervásio & Da Silva (2012)
	Assessment by experts through point scale	Qualitative	Hashemkhani et al. (2018) Kamali et al. (2018) Heravi et al. (2017) Rashidi et al. (2016) Balali et al. (2014) Chen (2014) Drejeris & Kavolynas (2014)Reyes et al. (2014) Lombera & Aprea (2010) Malekly et al. (2010) Dabous & Alkass (2008)
(xi) Innovations	Assessment by experts through point scale	Qualitative	Heravi et al. (2017) Ignatius et al. (2016) Drejeris & Kavolynas (2014)Yu et al. (2012) Ugwu & Haupt (2007) Gento (2004)
(xii) Culture	Assessment by experts through point scale	Qualitative	Hashemkhani et al. (2018) Kamali et al. (2018) Heravi et al. (2017) Rashidi et al. (2017) Fetanat & Khorasaninejad (2015)Yu et al. (2012) Afshar et al. (2011) Ugwu & Haupt (2007)

(xiii) Health and Safety	Injuries/output unit	Quantitative	Barros et al. (2015) Kucukvar et al. (2014) Jovanovic et al. (2009)
	Fatalities/output unit	Quantitative	Klein & Whalley (2015)
	Particulate Matter (PM) concentration (PM2,5 / PM10)	Quantitative	Santos et al. (2019) Nassar et al. (2016)
	Safety costs (€)	Quantitative	Gervásio & Da Silva (2012)
	Assessment by experts through point scale	Qualitative	Hashemkhani et al. (2018) Kamali et al. (2018) Pascal et al. (2017) Heravi et al. (2017) De la Fuente et al. (2017b) Blanco et al. (2016) Dobrovolskiiene & Tamosiuniene (2016)Rashidi et al. (2016) Rochikashvili & Bongaerts (2016)De la Fuente et al. (2016a) De la Fuente et al. (2016b) Cuadrado et al. (2015) Drejeris & Kavolynas (2014) Jato-Espino et al. (2014) Reyes et al. (2014) Akadiri et al. (2013) Pons & De la Fuente (2013) Pons & Aguado (2012) Afshar et al. (2011) Hashemkhani et al. (2011) Lombera & Aprea (2010) Dabous & Alkass (2008) Wang et al. (2008) Ugwu & Haupt (2007) Gento (2004)

Table-1.5 Major Social indicators and criteria

Out all the 83 reviewed articles, 34 manuscripts (almost 41% of total) reflects the impact of an infrastructure on the social wellbeing along-with other aspects such as public acceptance (Kamali et al., 2018; Dobrovolskiiene & Tamosiuniene, 2016; Hosseini et al., 2016; Montajabiha, 2016; Väisänen et al., 2016; Kaya & Kahraman,2010), social welfare and increase of incomes (Tahmasebi & Yazdandoost, 2018; Gumus et al., 2016; Fetanat & Khorasaninejad, 2015; Zavadskas et al., 2007),accessibility (Chhipi- Shrestha et al., 2017; Sun et al., 2013; Martin et al., 2007), or leisure (Gento, 2004). Additionally, considering the comfort of the users, assessment focused on building, roads and other infrastructural designs have also been done (Invidiata et al., 2018; Gilani et al., 2017; Heravi et al., 2017; Moussavi et al., 2017; Oses et al., 2017; Jato-Espino et al., 2014).

Aesthetics has emerged as a crucial aspect of social sustainability, closely linked to the societal acceptance of a project. This aspect has been deliberated in 26 articles, encompassing the aesthetic perception of the infrastructure itself and its harmonious integration into both urban (Hosseini et al., 2016; Cuadrado et al., 2015) and rural environments (Zavadskas et al., 2010, 2007).

It is undeniable that the construction and maintenance phases of infrastructure bring forth numerous job opportunities, both directly and indirectly. Sixteen papers elucidate how this surge in employment opportunities is closely linked to an improvement in social welfare. While the methodological guidelines for social life cycle assessments developed by UNEP/SETAC (2013) give preference to employment generated specifically for local communities rather than employment in general, it is a common practice in social life cycle assessments to use overall employment generation as an indicator of social sustainability (Navarro et al., 2018b; Hunkeler et al., 2008).

The impact of an infrastructure on the local development of a region has been evaluated in 16 papers. This assessment encompasses factors such as the rise in Gross Domestic Product (Zavadskas et al., 2010; Saparauskas, 2007), increased tourism (Sun et al., 2013; Afshar et al., 2011), and the regional economic benefits derived from the utilization of local materials and resources (Gilani et al., 2017; Väisänen et al., 2016; Akadiri et al., 2013; Ugwu & Haupt, 2007) within this social impact category.

Externalities resulting from the construction of infrastructure, particularly from infrastructure maintenance, have been taken into account in 33.7% of the examined studies. Effects such as traffic disruption (Santos et al., 2019; Rashidi et al., 2017; Balali et al., 2014; Chen, 2014; Mikawi, 1996) or the increase in vehicle operating costs due to detours (Gervásio & Da Silva, 2012; Dabous & Alkass, 2008; Mikawi, 1996) are consistently used as social indicators when evaluating the sustainability of bridge infrastructure. Other frequently assessed externalities include noise or dust pollution resulting from construction activities (Mosalam et al., 2018; Heravi et al., 2017).

Incorporating innovative concepts into infrastructure design is also regarded as a social indicator, aiming to foster societal progress and technological development. Nine articles have taken this aspect into consideration. The assessment of this impact is based either on a binary indicator, scoring 1 if the design includes patented materials or solutions (Mosalam et al., 2018; De la Fuente et al., 2017a; Pons et al., 2017), or relies on the expertise of a selected panel (Alwaer & Clemens-Croome, 2010; Ignatius et al., 2016).

(13.3%) of the examined papers include culture as a measure of social sustainability, with a specific focus on respecting the cultural heritage of a region (Hashemkhani et al., 2018; Kamali et al., 2018; Alwaer & Clemens-Croome, 2010; Yu et al., 2012; Heravi et al., 2017; Rashidi et al., 2017) or its traditional architecture (Gilani et al., 2017). Due to the challenges in quantitatively assessing cultural indicators (UNEP/SETAC, 2013), most authors depend on the knowledge of their chosen expert panels for the evaluation of cultural impacts (Heravi et al., 2017; Fetanat & Khorasaninejad, 2015; Afshar et al., 2011).

Health and safety practices are integrated into both construction and industry companies, not only to safeguard workers from fatalities and major injuries but also to protect infrastructure users from the risk of accidents. The impact of activities associated with the construction and maintenance of infrastructure on the safety of workers involved, as well as the health risks to infrastructure users, has been considered in 42 articles (50.6% of the total).

3 Literature Review

Authors	Title of Papers	Discussion/Conclusions/Findings
Rabindra Adhikari, Pratyush Jha, Lalit Bhatt, Dipesh Thapa, Davide Forcellini and Dipendra Gautam (2021)	Failure investigation of under construction prestressed concrete bridge in Chitwan, Nepal	The Thimura bridge construction faced a significant challenge – the embankment supporting the falsework (temporary structures) was built from poorly graded cohesionless sand, a common but risky material found along Nepalese riverbanks. This granular sand, ranging from fine silts to gravel, lacks binding properties and exhibits extremely low bearing capacity, especially when unsupported. Unforeseen Risks and Potential Consequences:Dry, loose sand like this is prone to displacement and settlement, particularly near the embankment edges. This could cause the falsework to sink due to shifting sand, compromising its stability.Vibrations from construction activities can further weaken the sand's shear resistance, potentially triggering sliding of the loose material, especially where piled high.The falsework must be specifically designed to accommodate potential settlements from both the superstructure's static load and the unstable embankment.If the specific mechanisms and limitations of the erection towers used aren't considered during prestressing, additional stability problems can arise. In conclusion, using readily available riverbank sand for the Thimura bridge's falsework embankment posed significant risks due to the material's inherent instability and vulnerability to vibration. To ensure the safety and success of the construction, careful consideration of settlement mitigation strategies, vibration control measures, and robust falsework design was crucial.
Elisa Khouri Chalouhi (2019)	Optimal design solutions of concrete bridges considering environmental impact and investment cost.	This comprehensive software package takes you from initial site analysis to detailed reinforcement design. It starts by optimizing span counts, pier placements, and connection types, then calculates the ideal deck dimensions based on Eurocode requirements. Additionally, it integrates FEM analysis and memory-optimization algorithms for smooth, efficient operation. his groundbreaking software leverages advanced algorithms to find the most cost-effective and environmentally friendly bridge design based on Eurocode standards. It seamlessly integrates with commercial FEM software for detailed structural analysis and boasts a smart memory system for faster processing and discrete variable handling. This software optimizes bridge design considering cost, environment, and Eurocodes. It includes modules for span/pier selection, deck dimensioning, FEM analysis, and reinforcement design.
Lorea García San Martín(2011)	Life Cycle Assessment of Railway Bridges.	Among environmental impacts, global warming reigns supreme, followed by eutrophication and abiotic depletion. This is largely driven by greenhouse gas emissions from steel, concrete, and timber production, with steel having the highest footprint. Timber, despite its disposal contributing to eutrophication, has a lower overall impact in this analysis. Both eutrophication and abiotic depletion are likely linked to material production, while ozone layer depletion and photochemical oxidation are negligible with this method. For a deeper dive into ozone layer depletion, EDIP might be a better choice, though it lacks abiotic depletion assessment.
Abdel-Basset, M., Manogaran, G., Mohamed, M., & Chilamkurti , N. (2018)	Three-way decisions based on neutrosophic sets and AHP-QFD framework for supplier selection problem.	Neutrosophic set represents the three-way decisions theory effectively, efficiently and more flexible than fuzzy and intuitionistic fuzzy sets. By studying the three-way decisions, two rules of decision making is proposed. An evaluation function of three- way decisions is presented to calculate weights of alternatives and an integrated neutrosophic AHP-QFD approach has been presented toselect the best supplier from different alternatives.

Authors	Title of Papers	Discussion/Conclusions/Findings
Navarro, I. J., Yepes, V., & Martí,J. V. (2018b)	Social life cycle assessment of concrete bridge decks exposed to aggressive environments.	Following a four-step assessment, our analysis of 15 concrete bridge deck designs reveals that those using stainless steel reinforcement or concrete enhanced with silica fume or polymers excel in social sustainability. This highlights the significant role maintenance-related social impacts play in a structure's overall sustainability performance.
Peng, J. J., Wang, J.,& Yang, W. (2017)	A multi-valued neutrosophic qualitative flexible approach based on likelihood for multi-criteria decision-making problems.	The preference relations of MVNNs based on likelihood were developed. Subsequently, based on the likelihood of MVNNs, an extended qualitative flexible multiple criteria method (QUALIFLEX)approach was proposed to deal with MCDM problems where the data are expressed by MVNNs. With the help of example demonstrating the application of the proposed decision-makingapproach, it is shown that the results are feasible and credible.
Braga, A. M., Silvestre, J. D., & deBrito, J. (2017)	Compared environmental and economic impact from cradle to gate of concrete with natural and recycled coarse aggregates.	Replacing fresh coarse aggregates with recycled ones in concrete significantly reduces both environmental impacts and costs, proving cement to be the primary culprit in both areas. Moreover, recycled concrete delivers superior mechanical properties, translating to lower long-term costs and environmental burdens.
Sarhosis, V., De Santis, S. and de Felice, G. (2016)	A Review of Experimental Investigations and Assessment Methods for Masonry Arch Bridges.	Three main areas of research are the characterization of the materials, the experimental testing on model bridges and real structures, and the structural assessment methods.Study provides reliable information on the safety level of a bridge and on its residual service life under traffic loads also considering the effects of ageing, deterioration and fatigue.
Zhang, Y., Wu, W. and Wang, Y. (2016)	Bridge Life Cycle Assessment with Data Uncertainty.	For bridges, normal distribution can be adopted to fit environmental substances and environmental impact in steel production. The distributions of the weighted value of human health damage, ecological system damage, resource and energy consumption can be represented by an approximate similar normal distribution function.
Abdullah, L., &Najib, L. (2016)	Sustainable energy planning decision using the intuitionistic fuzzy analytic hierarchy process: choosing energy technology in Malaysia	The new IF-AHP is applied to establish preference in the sustainable energy planning decision-making problem. Threedecision-makers attached with Malaysian government agencies were interviewed to provide linguistic judgement prior to analysing the new IF-AHP. Nuclear energy has been decided as the best alternative in energy planning which provides the highest among all the seven alternatives.
Ali, M., Aslam, M. S., & Mirza, M. S.(2016)	A sustainability assessment framework for bridges – a case study: Victoria and Champlain Bridges, Montreal	A summary of partial details of design, construction, maintenance and rehabilitation/renovation for the four versions of the 3-km longVictoria Bridge (1858, 1898, 1958 and 1988) is presented. All four versions of the Victoria Bridge were considered acceptable for bridge operations and whereas Champlain Bridge is found relativelyunsustainable.

Authors	Title of Papers	Discussion/Conclusions/Findings
Arya, C. Amiri, A and Vassie, P (2015)	A new method for evaluating the sustainability of bridges	The indictors used to assess sustainability are climate change, resources used, waste, biodiversity and heritage, noise, dust, vibration, aesthetics, employment and businesses, construction costs, maintenance costs and user delay costs. The results case study on the appraisal of three alternative designs of an over-bridge for adual two-lane motorway to discover which option is the most sustainable is presented. After providing the key input parameters individual impacts are combined to produce an overall sustainability score for a given structure is highlighted. The paper gives light on further improving the sustainability of the selected design.
Safi M., Du, G., Karourni, R., & Sundquist , H. (2015)	Holistic approach to sustainable bridge procurement considering LCC, LCA, User-cost and Aesthetics	A novel procurement approach is introduced to guarantee the most sustainable (life-cycle-efficient) bridge construction within D-B (Design Build) contracts. This method goes beyond traditional cost analysis by factoring in aesthetic appeal and environmental impact through additional techniques. This allows agencies to define monetary values for these crucial aspects during the initial planning phase and incorporate them as central specifications in tender documents. Ultimately, the project is awarded to the bid with the lowest net equivalent LCC, taking all sustainability factors into account.
Pang, B., Yang, P., Wang, Y., Kendall, A., Xie, H. and Zhang, Y (2015)	Life Cycle Environmental Impact Assessment of a Bridge with Different Strengthening Scheme.	Analyzing the environmental impact of different bridge maintenance and strengthening strategies revealed an interesting picture. Shockingly, the maintenance phase itself contributes a whopping 66% of the total impact, with detours alone accounting for half of that. Repaving and strengthening measures also play a role, adding 12% and 4% respectively. Notably, the four strengthening plans show a trade-off between cost and environmental impact. Some cheaper options, like steel plates, come at a cost to the environment, while more expensive solutions like carbon fiber-reinforced polymer have a significantly lower environmental footprint. Interestingly, the study concludes that bonding carbon fiber offers the most sustainable approach for bridge strengthening compared to traditional steel plates.
Torres-Machi, C., Chamorro, A., Pellicer, E., Yepes, V., & Videla, C. (2015).	Sustainable Pavement Management. Integrating Economic, Technical, and Environmental Aspects in Decision Making.	1. Don't overlook the full value of eco-friendly alternatives. Revising environmental cost assessments to include the broader social and economic benefits they provide can lead to more informed decisions. 2. The number of options and criteria can guide your choice of decision-making tool. AHP (Analytic Hierarchy Process) works well for smaller projects with less than seven factors, offering a structured approach to weighting priorities. For more complex situations with numerous options or criteria, consider methods like weighted sum or multi-attribute approaches that can handle larger data sets and nuanced trade-offs.
Yadaollahi, M., Ansari, R., Abd Majid, M. Z., & Yih, C. H. (2014)	A multi-criteria analysis for bridge sustainability assessment: a case study of Penang Second Bridge, Malaysia.	Different sustainability rating systems have unique priorities. This study built a custom hierarchy of bridge attributes for each system. Then, they used an analytical hierarchy process to assess the bridge's sustainability relative to those attributes. Overall, the bridge performed well, meeting most of the sustainability criteria across the various systems.
Kabir, G., Sadiq, R.,& Tesfamariam, S. (2014)	A review of multi-criteria decision making methods for infrastructure management.	The growing role of MCDM in infrastructure management is evident in this review. Not only has there been a significant surge in MCDM applications over the past decade, but the development of decision support tools combining multiple MCDM methods has proven highly effective.

Authors	Title of Papers	Discussion/Conclusions/Findings
Marzourk, M., & Azab, S. (2014).	Environmental and economic impact assessment of construction and demolition waste disposal using system dynamics. Resources, Conservation and Recycling.	The rising tide of construction waste poses a critical challenge. This study tackles this issue by developing a cutting-edge system dynamics model that assesses the economic and environmental consequences of waste management choices. By comparing recycling and disposal scenarios, the model reveals the substantial costs, both financial and ecological, associated with unmanaged waste. As a result, the research emphasizes CDW recycling as a key enabler for sustainable development, benefitting both the environment and the economy.
Bolzoni, F., Brenna, A., Fumagalli, G., Goidanich, S., Lazzari, L., Ormellese, M., & Pedeferri, M. P. (2014).	Experiences on Corrosion inhibitorsfor reinforced concrete.	The study confirms existing research: nitrite-based inhibitor effectively slows corrosion when the [NO-]/[Cl-] ratio exceeds 0.5-0.6. However, in carbonated concrete with insufficient inhibitor, no significant impact on corrosion rate was observed.
Reyes, J., San-José, J., Cuadrado, J., & Sancibrian, R. (2014).	Health and safety criteria for determining the sustainable value of construction projects.	This research introduces a methodology for effectively integrating health and safety (H&S) concerns into management projects from the design stage. This methodology utilizes a scoring system ranging from 0 to 1 that evaluates the project's sustainability level. Additionally, it presents the "Health and Safety Costs Index" (H&SC Index), a second tool based on economic criteria, that translates the initial score into quantifiable financial terms.
Barone, G., & Frangopol, D.(2014)	Life-Cycle Maintenance of Deteriorating Structures by Multi-Objective Optimization Involving Reliability, Risk, Availability, Hazard and Cost.	This research tackled the key challenge of optimizing maintenance plans for aging structures. They compared four distinct bi-objective optimization methods, two based on annual performance metrics and two using lifetime distribution models, both aiming for optimal availability and minimal hazard risk. Cost minimization acted as a secondary objective across all approaches.
Baltazar, L, Santana, J., Lopes, B., Rodrigues, M.P.,& Correia, J.R. (2014)	Surface skin protection of concrete with silicate-based impregnations: influence of the substrate roughness and moisture.	While silicate impregnations offer a strong shield against water and wear for concrete structures, they leave impact resistance vulnerable. Consider surface texture and moisture level when applying these treatments for optimal results.

Authors	Title of Papers	Discussion/Conclusions/Findings
By Balali, V., Mottaghi, A., Shoghli, O., & Golabchi, M. (2014).	Selection of appropriate material, construction technique, and structural system of bridges by use of multi criteria decision-making method.	Sustainability played a key role in selecting the materials and methods for the Kashkhan highway bridge. By employing the PROMETHEE method, engineers opted for a box girder system with post-tensioned concrete, constructed using the balanced cantilever method. This image captures the bridge's graceful form, while the chosen materials and construction technique offer environmental advantages compared to traditional approaches.
De Schepper, M., Van den Heede, P., Van Driessche, I., & De Belie, N. (2014)	Life cycle assessment of completely recyclable concrete.	High-Strength, Low-Clinker CRC: A champion in reducing greenhouse gas emissions! This combination can slash global warming potential by a staggering 66%-70% compared to standard concrete. Normal-Strength CRC: While not as dramatic, even regular-strength CRC with higher clinker content can offer reductions of 7%-35%, provided it has a sufficient lifespan. Every bit counts in the fight against climate change.
Du, G., & Karourni, R. (2014)	Life cycle assessment framework for railway bridges: literature survey and critical issues	This article revolutionizes LCA for railway bridges by introducing a comprehensive, user-friendly framework. It equips you with a step-by-step process for measuring emissions and energy consumption across the entire bridge lifecycle, while addressing major hurdles in modern LCA methods. With this powerful tool, you can optimize your projects for greener infrastructure and a more sustainable future.
Du, G., Safi, M., Petterson, L. and Karoumi, R. (2014)	Life Cycle Assessment as a Decision Support Tool for Bridge Procurement: Environmental Impact Comparison among Five Bridge Design.	It is imperative to acknowledge that despite the valuable insights garnered from this in-depth analysis of 20 environmental indicators across five bridge designs, drawing universal conclusions remains untenable. The outcomes of Life Cycle Assessments are demonstrably influenced by subjective monetary weighting systems, uncertainties in key variables like material recycling rates, and specific environmental contexts. For future research and practice to yield truly meaningful comparisons and guide sustainable bridge design, meticulous and transparent specification of these influencing factors is paramount.
Hu, M., Kleijn, R., Bozhilova-Kisheva, K. P., & Di Maio, F.(2013).	An approach to life cycle sustainability analysis (LCSA): the case of concrete recycling.	The C2CA-LCSA study offers valuable insights into applying a broad system perspective to standardize LCSA procedures. Its three-level sub-question categorization is particularly helpful. While providing initial steps for operationalizing the LCSA concept, it highlights the need for further case studies to solidify LCSA as a practical framework for complex sustainability analyses.
Thor, J., Ding, S., & Kamaruddin, S. (2013)	Comparison of Multi Criteria Decision Making methods from the Maintenance alternative selection perspective.	Choosing the best maintenance strategy for complex infrastructure can feel like navigating a labyrinth. Thankfully, Multi-Criteria Decision Making (MCDM) methods act as your trusty map, guiding you towards the optimal solution. This research paper takes a deep dive into four popular MCDM methods extensively used in maintenance decision-making: TOPSIS, VIKOR, PROMETHEE, and ELECTRE.
Gervásio, H. and da Silva, L. (2013)	A Design Approach for Sustainable Bridges – Part 1: Methodology.	This paper presents a novel approach to bridge design that blends two crucial perspectives: the financial lens of accounting and the strategic vision of decision-making. By integrating these viewpoints, it empowers engineers to create sustainable bridges that are not only cost-effective but also resilient and enduring.

Authors	Title of Papers	Discussion/Conclusions/Findings
Finnveden, G., Hakansson, C., & Noring, M. (2013).	A new set of valuation factors for LCA and LCC based on damage costs-Ecovalue 2012	This study showcases an enhanced Ecovalue method, bridging the gap with the Recipe approach for most categories and leveraging Cumulative Exergy Demand for abiotic resources. Analyzing an ICT product through this lens highlights the critical sustainability challenges of climate change, toxicity, and resource depletion, urging both manufacturers and consumers to prioritize these areas for improvement.
Thiebault, V., Du, G., & K.aroumi, R. (2013,2010).	Design of railway bridges considering LCA	This research delves into a simplified quantitative LCA approach for railway bridges, materialized in a user-friendly Excel tool. Utilizing this tool on two bridge designs from Sweden's Banafjäl Bridge project, the study meticulously analyzed a range of air and water pollutants across the entire life cycle. The results unequivocally revealed the fixed track alternative as the greener champion, demonstrating its superiority in all environmental impact categories.
Gjørv, O. (2013)	Durability design and quality assurance of major concrete infrastructure.	Failing to document compliance before accepting structures from contractors can jeopardize construction quality and future maintenance. Without proper service manuals, owners lack vital information for condition assessment and preventive maintenance, potentially leading to reduced durability and a shorter lifespan for the concrete structures.
Kim, S. H., Choi, M. S., Mha, H. S., & Joung, J. Y. (2013).	Environmental impact assessment and eco-friendly decision-making in civil structures.	This research delved into evaluating a bridge's environmental performance through two approaches: a comprehensive life-cycle assessment (LCA) and a user-friendly, eco-friendly decision-making procedure based on the Analytical Hierarchy Process. Although focusing on four key materials (steel, concrete, asphalt, and timber), the analysis covered the entire bridge lifecycle, offering a holistic perspective. Notably, the eco-friendly decision-making procedure helped normalize all environmental impact categories into a single, digestible indicator. This study also highlighted the significant influence of incorporating the recycling process into LCA calculations.
Du, G., & Karourni, R. (2013)	Life cycle assessment of a railway bridge: comparison of two superstructure designs	Unveiling a powerful new tool for assessing railway bridge sustainability: the Bridge LCA model. This model comprehensively analyzes environmental impacts from material extraction to end-of-life, empowering engineers to make informed design choices. To showcase its potential, the model tackles a real-world dilemma - comparing two alternative railway bridge designs. Utilizing the LCA CML 2001 method and diverse LCI databases, it provides a nuanced picture of their environmental footprints.
Safi, M. (2013).	Life-cycle costing: Applications and implementations in bridge investment and Management	This research unveils a comprehensive framework for applying Life Cycle Cost Analysis (LCCA) throughout the entire lifespan of bridges. Numerous case studies demonstrate how bridge management systems (BMS) can leverage LCCA to optimize decisions for both existing bridges and new construction. Additionally, a novel technique called "LCC Added-Value Analysis" empowers agencies to procure the most cost-effective bridge design through fair design-build tendering processes. These systematic analytical procedures and the potential for significant cost savings clearly highlight the feasibility and necessity of integrating LCCA into bridge management and procurement decisions.

Authors	Title of Papers	Discussion/Conclusions/Findings
Habert, G., Denarie, E., Sajna, A., & Rossi, P. (2013)	Lowering the global warming impact of bridge rehabilitations by using Ultra High Performance Fibre Reinforced Concretes.	This study evaluated a new rehabilitation system featuring an innovative UHPFRC with high limestone content. While its environmental impact comparable to traditional methods when not considering lifespan, the Eco-UHPFRC solution boasts a significantly lower Global Warming Potential (GWP) - even for a single rehabilitation cycle.
Akadiri, P. O., Olomolaiye, P. O.,& Chintio, E. A. (2013)	Multi-criteria evaluation model for the selection of sustainable materials for building projects	This paper unveils a novel building material selection model powered by the Fuzzy Extended Analytical Hierarchy Process (FEAHP). This robust method overcomes the challenges of sustainability assessment and weighting by incorporating the triple bottom line framework and stakeholder priorities. The result? A transparent, data-driven approach for navigating the complex world of sustainable building materials and making optimal choices for your specific needs.
SBRI-2013	Sustainable Steel-Composite Bridges in Built Environment	This research breaks new ground by merging functional quality with both environmental and economic aspects through a comprehensive life-cycle perspective. Leveraging LCP, LCA, and LCC methodologies, it delivers a complete picture of bridge performance. To empower practical application, a concise handbook details life-cycle performance, maintenance strategies, environmental impact, and cost analysis, making it user-friendly and readily implementable.
Padgett,J. E., & Tapia, C. (2013)	Sustainability of Natural Hazard Risk Mitigation: A Life-Cycle Analysis of Environmental Indicators for Bridge Infrastructure	LCS-A: A Holistic Approach to Bridge Resilience LCS-A goes beyond traditional bridge assessments by considering the environmental, social, and economic impacts throughout the entire life cycle, from construction to demolition. This includes: Mitigation of natural hazard risks: Earthquakes, floods, and other threats are factored in, with the framework evaluating various designs and retrofits for their effectiveness in safeguarding the bridge. Energy and emissions: The framework analyzes the embodied energy and greenhouse gas emissions associated with each design and retrofit option, guiding towards more sustainable choices.
Dequidt, T. (2012)	Life Cycle Assessment of a Norwegian Bridge	Tverlandsbrua, a majestic bridge standing tall, leaves its mark not just on the landscape but also on the environment. This analysis dives deep into its lifetime carbon footprint, offering insights into where we can build greener infrastructure in the future. The Big Picture:Tverlandsbrua's overall carbon footprint across its entire 100-year lifespan stands at 6665 kgCO2-eq per square meter of effective bridge deck area (FU).Excluding the operational phase (dominated by traffic emissions), the footprint drops significantly to 1358 kgCO2-eq per FU. Breaking Down the Impact:Production Phase: The champion of carbon emissions, responsible for a whopping 64.4% of the total footprint. Concrete, the backbone of the bridge, takes the spotlight as the main culprit.Construction Phase: Takes up 9.4% of the footprint, with lorry transportation of heavy elements (>16 tons) and concrete again being the

Authors	Title of Papers	Discussion/Conclusions/Findings
		primary contributors.Repair & Maintenance Phase: Demands 20.2% of the footprint, with asphalt maintenance emerging as the single biggest contributor, highlighting the importance of sustainable materials and practices in upkeep.End-of-Life Phase: Accounts for 6% of the footprint, with concrete dismantling, sorting, and transportation of disposal materials as the key offenders. Key Takeaways:Concrete's dominance across various phases emphasizes the need for exploring alternative materials or optimizing production processes.The operational phase, though excluded from the core analysis, highlights the significant role of traffic emissions in bridge sustainability.Understanding the breakdown of carbon footprint across different phases empowers targeted interventions for greener bridge design, construction, and maintenance.
Spencer, P., Hendy, C. and Petty, R. (2012)	Quantification of Sustainability Principles in Bridge Projects	This research unveils a game-changer: the sustainability index, a powerful tool to systematically quantify and improve the environmental, social, and economic performance of your bridges.Key Features of the Sustainability Index:Simple and transparent: No more deciphering complex calculations. The index is presented through a clear, graphical tool, making sustainability easily understandable and actionable.Targeted improvement: The index pinpoints areas where your design can be optimized, allowing you to focus your efforts for maximum impact.Comparative advantage: Evaluate different design options side-by-side, making informed choices for the most sustainable bridge solution.Real-time monitoring: Use the index throughout the design process to track the effectiveness of your decisions and adjust accordingly.Future-proof planning: Set ambitious sustainability targets based on the index rating, ensuring your bridges meet the demands of a greener future.
Du, G. (2012).	Towards sustainable construction: life cycle assessment of railway bridges	This research dives deep into the complex world of bridge sustainability, offering valuable insights for engineers, architects, and anyone passionate about building greener infrastructure. Key Findings: Bridge type matters: Your choice of bridge structure significantly impacts its environmental footprint throughout its entire life cycle. This means there's no one-size-fits-all solution to green bridges.Go beyond generalizations: Analyzing specific case studies using Life Cycle Assessment (LCA) is crucial. Don't rely on generic conclusions about bridge types – each project deserves its own in-depth evaluation.Spotlight on materials: The "birth" of bridge materials – manufacturing and transportation – often emerges as the biggest environmental burden. Choosing sustainable materials and optimizing production processes become key strategies.Data: the missing piece: Lack of readily available inventory data and project information can hinder comprehensive LCA studies. Addressing this data gap is essential for accurate and impactful assessments.

Authors	Title of Papers	Discussion/Conclusions/Findings
Habert, G., Arribe, D., Dehove, T., Espinasse, L., & LeRoy, R. (2012).	Reducing environmental impact by increasing the strength of concrete: quantification of the improvement to concrete bridges.	This research tackles the crucial question: can high-performance concrete (HPC) help us build more sustainable bridges? The answer is a resounding yes, with some fascinating caveats. Unpacking the Environmental Trade-Off:HPC boasts superior strength, allowing for less concrete per bridge. This reduces the overall material footprint, which benefits the environment.However, HPC production often emits more CO2 compared to traditional concrete. This trade-off requires careful analysis.Life Cycle Assessment: Taking the Long View:The study goes beyond immediate CO2 emissions, employing a comprehensive Life Cycle Assessment (LCA) to consider the bridge's entire lifespan. This holistic approach includes:Five key environmental impact indicators: covering resource depletion, acidification, human toxicity, ecosystem quality, and global warming potential (GWP).CML methodology: a standard LCA framework for robust and comparable results.
Mirzaei, Z., Adey B.T., Klatter, L., & Kong, J. (2012).	The IABMAS Bridge Management Committee Overview of Existing Bridge Management Systems	Report offers a comprehensive high-level view of bridge management systems, outlining their key components and functionalities. While it does not delve into the specifics of individual procedures, it highlights the potential benefits of a standardized approach, including streamlined integration of new features and fostering continuous improvement in system development.
Wilmers W. (2012)	Restoration of Masonry Arch Bridges: Proceedings of the Institute of Civil Engineers – Journal of Bridge Engineering.	This comprehensive report delves into the preservation of masonry arch bridges, analyzing over 30 structures and detailing best practices for their inspection, assessment, and repair. From scrutinizing foundations and masonry to optimizing hydraulics and pavements, the study offers a holistic approach to safeguarding these historical bridges. Notably, it explores innovative techniques like specialized mortars, stabilizing chemicals, and lightweight concrete internal arches for bridge strengthening, along with effective pavement reconstruction and moisture sealing strategies.
Zhang, C., Amaduddi n, M.and Canning, L.(2011)	Carbon dioxide Evaluation in a Typical Bridge Deck Replacement.	Paper tackles the vital question of reducing carbon footprint in bridge deck replacement. It comprehensively compares two options for a typical UK highway project, including a pioneering fiber-reinforced polymer (FRP) alternative. Beyond embodied carbon, it delves into future maintenance emissions and investigates the impact of variable traffic diversion via parametric analysis. Ultimately, it equips engineers with practical "green" strategies and transparently discusses potential limitations.
Dette, G., & Sigrist, V. (2011)	Performance indicators for concrete bridges.	Infrastructure management struggles with a crucial blind spot: the lack of well-defined performance indicators beyond technical aspects. This paper tackles this head-on, filling the void left by the Draft Model Code 2010. It builds a comprehensive framework encompassing not just functionality, economics, and environment, but also user costs and aesthetics, two societal impacts often neglected yet vulnerable to deterioration. Through a practical bridge engineering example, it demonstrates how these indicators illuminate the path towards optimal infrastructure management strategies.

Authors	Title of Papers	Discussion/Conclusions/Findings
Afshar, A., Marino, M., Saadatpour, M.,& Afshar, A. (2011)	Fuzzy TOPSIS multi criteria decision analysis applied to Karun reservoirs system.	This research breaks new ground by proposing a multi-criteria decision-making approach for water management that goes beyond the water system itself. It recognizes the interconnectedness of water with crucial socioeconomic, ecological, environmental, legislative, and political factors, ensuring holistic and responsible decision-making.
Ahlorth, S., & Finnveden, G (2011)	A new valuation set for environmental systems analysis tools	Moving beyond subjective valuations, this research introduces a novel environmental weighting set grounded in real-world data. Drawing on willingness-to-pay studies for environmental quality and established market values for resource depletion, it provides a robust and data-driven foundation for CBA in sustainable development projects.
Ahlorth, S., Nilsson, M., Finnveden, G.,Hjelm, 0., & Hochschomer, E. (2011).	Weighting and valuation in selected environmental systems analysis tools-suggestions for further developments	This paper delves into the prevalence and potential of weighting methods in Environmental Systems Analysis Tools (ESATs). By analyzing select tools, it sheds light on how weighting is currently used and proposes promising avenues for future development in this crucial area.
Hammervold,]., Reenaas, M., & Brattebø, H. (2011,20 09).	Environmental Life Cycle Assessment of Bridges.	This research, through a detailed LCA, reveals the environmental trade-offs of three bridge designs: steel box girder, concrete box girder, and wooden arch. While concrete emerges as the overall champion across most environmental impact categories, wood shines brightest in tackling global warming.
Zhang, C. (2010)	Delivering Sustainable Bridges to help Tackle Climate Change	This research delves into the environmental impact of bridges, pinpointing major CO2 emission sources throughout their life cycle. By analyzing these aspects, the paper identifies key areas for improvement, empowering bridge designers to adopt sustainable strategies and build eco-friendly bridges. Highlighting the slow pace of sustainability within the sector, it further proposes practical measures to accelerate positive change.
Botniabanan A.B. (2010)	Environmental product declaration for railway bridges on the Bothnia line.	This Environmental Product Declaration (EPD) offers a comprehensive, cradle-to-grave analysis of the environmental impact of railway bridges on the Bothnia Line. By encompassing both life cycle stages and total environmental footprint, it equips experts and scientists with objective, reliable data on construction, operation, and maintenance impacts.
Pacheco, P., Antonio, P., Fonseca, A., Resende, A. and Campos, R. (2010)	Sustainability in Bridge Construction Processes	This research goes beyond the technical prowess of Organic Prestressing System (OPS) technology in bridge construction, highlighting its remarkable contribution to increased sustainability. Alongside its technical advantages, OPS paves the way for eco-friendly infrastructure, making it a compelling choice for the future of bridge building.

Authors	Title of Papers	Discussion/Conclusions/Findings
Bouhaya, L., Le Roy, R., & Feraille-Fresnet, A. (2009).	Simplified environmental study on innovative bridge structure	This research explores the environmental footprint of an innovative bridge using wood and ultra-high performance concrete. While it boasts superior strength, maximizing both low environmental impact and high performance proved elusive. Designers can now choose, based on their priorities, between wood recycling's excellent CO2 performance and the higher energy benefits of burning wood, albeit with the worst CO2 impact.
Hung, M. L., & Ma, H. (2009)	Quantifying system uncertainty of life cycle assessment based on Monte Carlo simulation.	This municipal waste management case study sheds light on a crucial issue: different LCIA methods lead to different results! Choosing the right one, therefore, emerges as a major source of uncertainty in environmental impact assessment. This highlights the need for careful selection and transparency in LCIA methodology.
Wang, Y., Liu, J., & Elhag, T. (2008).	An integrated AHP-DEA methodology for bridge risk assessment.	This paper breaks new ground with the AHP-DEA methodology, an integrated approach to efficiently evaluate risks in hundreds or thousands of bridge structures. By leveraging AHP for weight determination and DEA for linguistic term valuation, it avoids cumbersome pairwise comparisons while maintaining accuracy. Ultimately, it generates overall risk scores for prioritizing bridge maintenance, maximizing value with minimal effort.
Gervasio, H., & Simoes da Silva, L.(2008).	Comparative life-cycle analysis of steel-concrete composite bridges.	This paper tackles two key objectives: (1) developing a comprehensive integrated methodology for life-cycle and sustainability analysis (LCA and LCCA), and (2) showcasing its application through a case study of a composite bridge.
Dabous, S., & Alkass, S. (2008)	Decision support method for multi-criteria selection of bridge rehabilitation strategy.	To ensure the real-world effectiveness of our newly developed decision support method for bridge deck improvement projects, we applied it to a real case study. The results were conclusive: the method successfully evaluated all available MR&R alternatives and delivered reliable and feasible recommendations for choosing the best option.
Lim, S. R., Park, D., & Park, J. M. (2008).	Environmental and economic feasibility study of a total waste-water treatment network system.	This research breaks new ground by evaluating the feasibility of a comprehensive network (TWTNS) for handling wastewater in iron and steel plants. Using advanced tools like LCA and LCC, it analyzes the environmental and economic impacts of both distributed and centralized treatment plants within the network. By comparing it to traditional systems, the study paves the way for a more sustainable and efficient approach to wastewater management in this vital industry.
Kendall, A., Keoleian, G. A., & Helfand, G. E. (2008).	Integrated life-cycle assessment and lifecycle cost analysis model for concrete bridge deck applications.	While the initial cost and environmental impact per unit material might be higher, this study reveals that an engineered cementitious composite link slab design for bridge decks ultimately proves more sustainable and cost-effective over the entire life cycle compared to a conventional concrete deck.
Sleeswijk, A.W., van Oers, L. F., Guinee, J. B.,	Normalization in product life cycle assessment: An	Analyzing 860 environmental interventions, this study reveals a surprising concentration of impact. Just 48 interventions account for at least 75% of the impact across 15 categories, highlighting the power of focusing on key areas like climate change and emissions.

Authors	Title of Papers	Discussion/Conclusions/Findings
Struijs, J., & I Juijbregts, M. A. (2008).	LCA of the global and European economic systemsin the year 2000.	Focus on the importance of tackling specific emissions:Curbing the big 10: This research pinpoints 10 major culprits - CO2, CH4, SO2, NOx, NH3, PM10, NMVOC, and (H)CFCs emissions in air, and N- and P-compounds in water – responsible for most non-toxic impacts. Prioritizing measures to control these emissions promises significant environmental gains. Focus on the need for improved data on toxic emissions:Toxic blind spots: While emission-related impacts are well-understood, our knowledge gap on toxic emissions remains vast. Limited data on pesticides, organics, and metals leads to large uncertainties in their impact assessment, calling for increased registration and research efforts. Focus on the study's implications for policy and action:Efficiency through focus: This study provides a roadmap for efficient environmental action. By identifying the high-impact interventions and knowledge gaps, it emphasizes the need for targeted policies, emissions control measures, and improved data on toxic emissions to maximize our environmental impact reduction efforts.
Long, A., Basheer, P., Taylor, S., Rankin, B. and Kirkpatri ck, J. (2008)	Sustainable Bridge Construction through Innovative Advances.	This research unveils exciting possibilities for concrete in bridge construction. Enhanced in-situ tests guide us towards more durable designs, advanced understanding of arching action paves the way for virtually maintenance-free systems, and the innovative "flat pack" flexible concrete arch system offers efficiency and potential cost savings. These advancements promise a future where concrete bridges stand not just tall, but also resilient and sustainable.
Melbourne, C., Tomor, A. and Wang, J. (2007)	A New Masonry Arch Bridge Assessment Method (SMART)	This paper introduces the SMART method, a powerful tool for identifying critical parameters in structural assessments. Using a practical example, it demonstrates how SMART pinpointed longitudinal shear stress as the key factor influencing ultimate load capacity and permissible axle loads, paving the way for informed decision-making.
Lundie, S., Huijbregts, M. A., Rowley, H. V., Mohr, N.]., & Peitz, A.]. (2007).	Australian characterization factors and normalization figures for human toxicity and ecotoxicity	This study tailors the existing USES-LCA 2.0 model to calculate impact factors for toxic chemicals released in Australia. By analyzing emission data from the National Pollutant Inventory and pesticide use information, it establishes normalization values for both ecotoxicity and human toxicity specific to the Australian context.
Hallbcrg, D., & Racutanu, G. (2007).	Development of the Swedish bridge management system by introducing a LMS concept	While the current system excels in operational, tactical, and strategic management, it lacks the functionality for optimizing and planning long-term MR&R actions based on service life performance. This research addresses this gap by emphasizing the need for service life analysis and proposing a model to effectively manage different degradation characteristics.

Authors	Title of Papers	Discussion/Conclusions/Findings
Lounis Z., & Daigle L. (2007).	Environmental benefits of life cycle design of concrete bridges.	This paper champions a transformative approach to bridge construction, advocating for life cycle-based design and maintenance. Not only does this lead to high-performance bridges, but it also minimizes environmental impact. By embracing innovative practices and materials, we can build future-proof infrastructure that endures, reduces costs, and protects our planet..This research unlocks the potential of industrial byproducts like fly ash, slag, and silica fume. By cleverly incorporating them into high-performance concrete (HPC), we can create bridge decks that last longer, cost less, and boast superior environmental credentials compared to traditional concrete.
Ugwu, O., & Haupt, T. (2007)	Key performance indicators and assessment methods for infrastructure sustainability – a South African construction industry perspective.	This research tackles the challenge of efficient infrastructure development in developing countries. By identifying key performance indicators (KPIs) for timely delivery and mapping computational methods for achieving sustainable objectives, it provides a practical framework for evaluating and optimizing infrastructure design proposals. This paper takes a data-driven approach to evaluating infrastructure sustainability. It utilizes multi-criteria decision analysis (MCDA) techniques like the "weighted sum model" and the analytical hierarchical process (AHP) with its "additive utility model" to develop a comprehensive "sustainability index." This index, based on carefully selected KPIs, guides the selection of optimal infrastructure designs in developing countries.
Frischknecht, R.; Jungbluth, N.; Althaus, H. J.; Doka, G.; Dones, R.; Hellweg, S.; Hischier, R.; Humbert, S.; Margni, M., & Nemecek, T. (2007).	Implementation of Life Cycle Impact Assessment Methods.	This report lays the groundwork for understanding how various environmental impact assessment methods can be applied to life cycle inventory data from the ecoinvent database. Part one offers a comprehensive overview of the general assumptions behind each method, while part two delves deeper into the specific implementation details of methods like Cumulative energy demand, Eco-indicator 99, and many others. This report unveils a treasure trove of diverse impact assessment methods, from Cumulative exergy demand to IPCC 2001 for climate change. By showcasing both established classics like Eco-indicator 99 and innovative newcomers like IMPACT 2002+, it provides a comprehensive resource for anyone seeking to evaluate the environmental footprint of their products or processes.
Saparauskas, J. (2007)	The main aspects of sustainability evaluation in construction.	While numerous studies tackle specific building and construction issues, assessing industry-wide sustainability in countries like Lithuania remains underexplored. This research fills this gap by developing a unique indicator system based on six socio-economic and environmental factors. Recognizing the multi-faceted nature of sustainability, this research employs both TOPSIS and SAW multi-criteria decision-making methods. The good news? Both approaches reveal a positive trend: Lithuania's construction industry is generally moving towards sustainable practices.
Collings, D. (2006).	An environmental comparison of bridge forms.	This study takes a comprehensive approach to assessing the environmental impact of bridge construction and maintenance. Using a case study of a river bridge, it compares the embodied energy and CO2 emissions of various bridge forms (girder, tied arch, cable-stayed) and materials (concrete, steel, composite) across the entire life cycle, including construction, maintenance, and repairs. This research goes beyond simply measuring the environmental impact of bridges. By analyzing the variability of embodied energy and CO2 emissions in different materials and forms, it provides valuable insights for optimizing bridge design. This knowledge empowers engineers and policymakers to make informed choices that minimize the environmental footprint of our infrastructure.
Guettala, A. and Abibsi, A. (2006)	Corrosion Degradation and Repair of a Concrete Bridge.	This paper uncovers the story of a reinforced concrete bridge, analyzing the effects of a diagnostic and repair process and finally assessing its post-repair condition. The investigation pinpointed chemical attack by chloride ions as the culprit behind reinforcement corrosion and concrete cracking, highlighting the crucial role of ongoing maintenance and inspection in ensuring bridge

Authors	Title of Papers	Discussion/Conclusions/Findings
		longevity. This study sheds light on the insidious threat posed by chloride ion infiltration in reinforced concrete bridges. By examining the degradation of bandages and piers on a specific bridge, the research reveals how this chemical attack leads to reinforcement corrosion and ultimately concrete bursting. The findings underline the urgent need for proactive maintenance and inspection to combat this silent enemy and preserve bridge integrity.
Bare, J. C., & Gloria,T. P. (2006).	Critical analysis of the mathematical relationships and Comprehensiveness of life cycle impact assessment approaches.	Navigating the complex world of life cycle impact assessment (LCIA) methodologies just got easier. This research offers a comprehensive review of popular approaches, dissecting them clearly for non-experts. By providing insightful comparisons across midpoint, endpoint, damage, and weighting levels, it empowers practitioners to make informed choices when selecting the right tool for their needs. This paper delves into the inner workings of popular LCIA methods, exposing the motivations and perspectives behind each approach.
CIRIA Guide (2006)	Masonry Arch Bridges: Condition Appraisal and Remedial Treatment	Masonry arch bridges demand special care. While these grand structures may stand resilient, ensuring their continued service requires more than just routine maintenance. Their unique needs and distinct characteristics call for dedicated management and a specialized approach, distinct from that of modern bridges. Investing in specialist knowledge and understanding is crucial for their effective stewardship and continued contribution to our infrastructure.
Shen, L. Y., Lu, W. S., Yao, H., & Wu,D. H. (2005)	A computer-based scoring method for measuring the environmental performance of construction activities	This paper unveils a novel scoring method, delivered through an IT-supported program, that empowers contractors to track and improve their environmental performance. The EPS system goes beyond calculating a score; it delves deeper, helping contractors diagnose the root causes of potential environmental issues and guiding them towards greener practices. This research not only conceptualizes the EPS system but also brings it to life through a simulated case study. By showcasing its practical application in a controlled environment, the study demonstrates how the EPS system can effectively assess and guide contractors towards improved environmental performance in the real world.
Kiker, G., Bridges, T., Varghese, A., Seager, P. and Linkov, I. (2005)	Application of Multicriteria Decision Analysis in Environmental Decision Making.	This paper serves as a comprehensive guide to using multi-criteria decision analysis (MCDA) methods in environmental contexts. It not only showcases existing applications but also equips you with the tools to tailor your own MCDA framework. You'll learn about vital components, process selection, and practical implementation, empowering you to make informed and sustainable choices while considering people, processes, and available tools.
Jin, N., Chryssanthopolo us, M. and Parke, G.(2005)	Bridge Management Using Principles of Whole Life Cost and Life Cycle Assessment Subject to Uncertainty.	This study tackles the challenge of managing bridges by considering both financial and environmental consequences throughout their lifespan. It proposes a novel methodology that combines whole life costing with life cycle assessment and empowers decision-makers to choose the optimal maintenance scenario based on their priorities.
Itoh, Y., Wada, M., & Liu, C., (2005).	Lifecycle environmental impact and cost analyses of steel bridge piers with seismic risk.	This paper expands current life cycle analysis (LCA) methods for the construction and maintenance of buildings, taking the critical factor of seismic recovery after earthquakes into account. By integrating a probabilistic earthquake occurrence method, novel seismic fragility curves, and real earthquake damage data, this research offers a more comprehensive and realistic picture of environmental impact and costs over a building's lifespan.

Authors	Title of Papers	Discussion/Conclusions/Findings
Keoleian, G. A., Kendall, A., Dettling, J. E., Smith, V. M., Chandler, R. F., Lepech, M. D., & Li, V. C., (2005).	Life Cycle Modelling of Concrete Bridge Design: Comparison of Engineered Cementitious Composite Link Slabs and Conventional Steel Expansion Joints	This study proves that ECC link slabs significantly reduce environmental impact compared to traditional steel expansion joints over a 60-year lifespan. This, combined with the material selection and design tools presented in the paper, empowers engineers to build greener, more sustainable bridges. This paper doesn't just highlight the environmental benefits of ECC link slabs; it provides practical tools to implement them. The material selection methodology and LCA model offer architects and engineers a roadmap for designing and evaluating sustainable bridges, ultimately leading to better investment decisions in infrastructure.
Stewart, M. G., Estes, A. C., & Frangopol, D. M. (2004).	Bridge deck replacement for minimum expected cost under multiple reliability constraints.	This analysis delves into the hidden complexities of bridge performance, considering not just design specifications but also the variability of materials, loads, dimensions, modeling errors, and even environmental factors like chloride penetration and corrosion. By accounting for these uncertainties across both ultimate strength and serviceability criteria, it reveals the potential hidden costs inherent in a simplified, single-limit-state approach. This research challenges the traditional focus on ultimate strength as the sole metric for bridge design. By demonstrating how factors affecting serviceability (like deflection and cracking) can significantly impact life-cycle costs, it advocates for a holistic approach that considers both strength and serviceability limit states. This comprehensive perspective can lead to more cost-effective and resilient bridges in the long run.
Martin, A. J. (2004).	Concrete bridges in sustainable development.	This paper unveils the intricacies of sustainable concrete bridge construction, offering valuable insights for bridge owners, designers, builders, maintainers, and even users. It presents a structured approach to tackling sustainability challenges and explores the vital role of concrete in building environmentally responsible bridges. This research goes beyond the traditional focus on durability, delving into the four pillars of sustainable thinking – natural resources, environment, society, and economics. Through the lens of concrete bridge construction, it explores how design, construction, and maintenance choices can contribute to a greener future.
Sustainable bridges (2004)	European Railway Bridge Demography	Our expansive survey, covering nearly all of Europe and its distinct climatic zones, reveals a fascinating picture of the continent's railway bridge stock. Despite a general trend towards aged structures, a surprising variety of bridge types still stands strong. Brick arch bridges reign supreme, followed closely by both metallic and concrete contenders, while composite bridges hold a smaller, yet noteworthy, spot. The majority of Europe's railway bridges keep things short and sweet, comfortably spanning less than 10 meters. While only 5% stretch beyond 40 meters, those giants tend to favor metallic construction for their formidable spans.
Arskog, V., Fossdal,S., & Gjørv, O. E. (2004).	Life-cycle assessment of repair and maintenance systems for concrete structures.	This paper unveils a tool for choosing sustainable repair methods for concrete structures. By analyzing the environmental impact of different repair materials and systems, it empowers engineers to minimize their ecological footprint. The research paints a clear picture: opting for preventive maintenance before extensive repairs become necessary is the key to building and maintaining structures in harmony with the environment. This research equips engineers with a practical framework for quantifying the environmental impact of various repair materials and systems. Preventive maintenance emerges as the green champion, offering significant environmental benefits compared to reactive repairs.

Authors	Title of Papers	Discussion/Conclusions/Findings
Rebitzer G., Ekvall T., Frischknecht R., Hunkeler D., NorrisG., Rydberg T., Schmidt W. P., Suh S., Weidcma B.P., Pennington D.W. (2004).	Life cycle assessment Part 1: Framework, goal and scope definition, inventory analysis, and applications.	This research lays the groundwork for any LCA study with its robust framework: a crystal-clear goal and scope definition followed by a meticulous inventory analysis. The paper further sheds light on the current state of these foundational elements and opens doors to practical applications of LCA across diverse fields. Part one of this paper, authored by the author and colleagues, establishes the essential building blocks of LCA: setting clear goals and boundaries, then conducting a comprehensive inventory analysis. Part two, led by Pennington et al. (2004), delves deeper into the impacts arising from the identified resource consumption and waste/emissions inventories.
Pennington D., Potting J., Finnveden G" Lindeijer E.,Jolliet0., Rydberg T. and Rebitzer G. (2004)	Life Cycle Assessment part 2: Current impact assessment practice.	Examining the intricacies of the Life Cycle Impact Assessment (LCIA) phase, this research highlights the diverse modeling options and methodologies available for transforming life cycle inventory data into impactful environmental indicators. This research empowers practitioners by demystifying the various LCIA methods and their underlying models. By outlining their differences and strengths, it provides a valuable roadmap for selecting the right tool for calculating accurate and meaningful environmental impact indicators.
Baumann, H. & Tillman, A-M. (2004).	The hitchhiker's guide to LCA	This comprehensive book delves into every aspect of LCA, from a wide range of methodologies to their practical applications in diverse fields like product development, marketing, production, and waste management. Environmental professionals will gain not only the skills to interpret LCA results but also the in-depth knowledge to apply them in real-world situations. Dive into practical exercises designed to prepare you for tackling complex LCA projects with confidence.
Steele, K., Cole, G., Parke, G., Clarke,B., & Harding, J. (2003)	Highway bridges and environment sustainable perspectives.	This report challenges a common assumption, revealing that frequent bridge maintenance, with its associated closures and detours, can actually significantly increase environmental impact. It introduces a life-cycle assessment method that helps identify the optimal maintenance strategy for minimizing environmental footprint while ensuring structural integrity. It showcases how factors like traffic disruptions and detours caused by regular maintenance can contribute to a surprisingly high environmental burden. The proposed life-cycle assessment method offers a tool for making informed decisions that account for both direct and indirect environmental impacts.
Itoh,Y., & Kitagawa, T. (2003).	Using CO2 emission quantities in bridge lifecycle analysis	Study demonstrates that minimized girder bridges offer a clear advantage over conventional bridges, both in terms of environmental impact and cost. By employing a modified life cycle assessment methodology, we found that minimized girder bridges produce significantly lower CO2 emissions and are more cost-effective throughout their lifespan. Accelerated exposure testing revealed a significant relationship between fog salt exposure and weight loss in steel samples. Notably, we were able to model this relationship mathematically, allowing us to predict the average thickness decrease due to fog salt for vertically placed steel elements. This simple formula has valuable implications for designing and maintaining steel structures exposed to harsh environments.
Steele, K. N. P., Cole, G., Parke, G., Clarke, B., & Harding, J. (2002).	The Application of Life Cycle assessment Technique in the Investigation of Brick Arch Highway Bridges.	This paper comprehensively examines all stages of a bridge's life cycle, from initial construction to years of service, culminating in the eventual need for either strengthening or replacement due to obsolescence. We delve into the challenges and opportunities presented at each stage, particularly highlighting the crucial role of bridge strengthening technologies.

Authors	Title of Papers	Discussion/Conclusions/Findings
Godart, B. and Vassie, P. (2001)	Bridge Management Systems: Extended review of Existing Systems and outline Frameworkfor a European System.	This survey reveals that computerized bridge management systems (BMS) are widely used across the continent, with 11 out of 16 responding countries employing them. While three are actively developing their own systems, only two rely on partially automated approaches. These findings highlight the importance of efficient bridge management for European infrastructure.
Worrell, E., Price, L., Martin, N., Hendriks, C., & Meida, L. O. (2001).	Carbon dioxide emissions from the global cement industry.	In 1994, the world's hungry appetite for cement generated a staggering 307 million metric tons of carbon emissions, constituting a significant 5% of all human-caused CO2 emissions that year. China spearheaded this, producing a whopping one-third of the global total, followed by the United States, India, Japan, and Korea. Notably, the top 10 cement-producing countries collectively contributed a hefty 63% to these emissions.
Fowler, D.W. (1999)	Polymers in concrete: a vision for the 21st century.	PIC, PC, and PMC have been taking the construction world by storm for the past 25 years. These versatile materials, used for repairs, overlays, and precast elements, offer enhanced performance compared to traditional concrete. While limitations like cost, odor, and safety concerns exist, the future promises exciting advancements in materials, applications, and uses.
Widman, J. (1998).	Environmental impact assessmentof steel bridges.	Studies by the Swedish Institute of Steel Construction show that steel bridges require less material than concrete bridges, significantly reducing their environmental footprint.
M.A. Issa, A.K. El-Shakour, and M.C. Chiew (2023)	Durability of Ultra-High-Performance Concrete (UHPC) in Prestressed Concrete Bridge Decks.	UHPC's remarkable resilience against freeze-thaw cycles and chloride attack paves the way for a revolution in bridge deck construction. Its dense microstructure, exceptional strength, and optimized pore structure create an impenetrable barrier against environmental threats, promising longer lifespans, reduced maintenance costs, and ultimately, superior bridge performance. This innovative material boasts a tightly packed microstructure, minimizing entry points for harmful substances. Its unmatched compressive strength offers robust resistance to external stresses and environmental factors, while the optimized pore structure acts as a final line of defense. This multi-layered protection translates to dramatically reduced deterioration, making UHPC a game-changer for future bridges.
S.Y. Hong, Y. Liu, and Y.C. Teng (2023)	Long-Term Monitoring of Prestress Losses in a Segmental Concrete Bridge	Contrary to expectations, a long-term study shows much lower prestress losses in a segmental concrete bridge than traditional calculations predict. This suggests existing design methods might be overly conservative, opening doors for leaner, more economical bridge designs in the future. Even with lower-than-expected prestress losses, the bridge maintained its structural integrity throughout the monitoring period. This confirms the inherent sturdiness of the design and construction, while also suggesting potential for future optimization that enhances both safety and cost-effectiveness.
Horvath, A. & Hendrickson, C. T(1998)	Steel vs Steel-Reinforced Concrete Bridges: Environmental Assessment	While the reusability of steel suggests a lighter environmental footprint compared to concrete, Malin (1997) warns of a potential twist. The growing prevalence of mini-mills, which primarily use recycled steel scrap, could significantly reduce the resource inputs and environmental impact of steel production compared to traditional integrated mills. If this is true, the study's results may underestimate the environmental advantages of steel bridges.

Authors	Title of Papers	Discussion/Conclusions/Findings
Thompson, P., Small, P., Johnson, M. and Marshall, A. (1998)	The Pontis Bridge Management System.	This advanced bridge management system leverages the power of Markov decision processes and linear solutions to tackle complex network optimization challenges. As a result, Pontis empowers effective planning and execution of preventative measures, safeguarding the durability and functionality of U.S. bridges.
Page, J. (1996)	A Guide to Repair and Strengthening of Masonry Arch Highway Bridges	This in-depth guide delves into the challenges faced by arch bridges, presenting a plethora of repair and strengthening options tailored to diverse issues. It equips you with the knowledge to assess bridge conditions, gather essential data, and implement effective strengthening measures - all supported by cost considerations.
Mikawi, M. (1996).	A methodology for the evaluation of the use of advanced composites in structural civil engineering applications	This research unveils a new tool for evaluating advanced materials in civil engineering, specifically targeting their potential for repairing and strengthening aging bridge columns. This multi-criteria approach, powered by the Analytical Hierarchy Process (AHP), empowers engineers to make informed decisions about leveraging cutting-edge materials, contributing to the longevity and resilience of our infrastructure. By developing a systematic approach to assess their suitability for repair and strengthening, particularly in bridge columns, the study tackles the pressing need for sustainable infrastructure solutions. This reduces the pressure on building new structures while extending the lifespan of existing ones.
Bertolini, L., Bolzoni, F., Pastore, T., & Pedeferri, P. (1996).	Behaviour of stainless steel in simulated concretepore solution.	This study analyses the performance of various stainless steel rebars in highly aggressive concrete settings. By subjecting them to a range of pH levels, chloride concentrations, and temperatures, researchers explored the impact of these factors on the critical chloride content, highlighting the influence of composition and temperature. Additionally, the beneficial role of high carbonate/bicarbonate concentrations is revealed. The study analyzes how steel composition, temperature, and surrounding environment influence resistance to chloride-induced corrosion, providing valuable insights for selecting the most suitable material for long-lasting structures.
Heijungs, R. and Guinée, J. (1994)	Software as a Bridge between Theory and Practice in Life Cycle Assessment.	This study emphasizes the pitfalls of relying on implicit knowledge within computers or even among computer specialists. Only through meticulous and open communication of LCA methods and everyday practices can we ensure the development of computer models that truly fulfill their potential. Achieving accurate LCA models relies on a strong partnership between domain experts and computer specialists. This research underscores the importance of transparent communication, ensuring that LCA specialists articulate their needs and methodologies clearly, while computer specialists translate them into robust and reliable models.
Ashurst, D. (1993)	An Assessment of Repair and Strengthening Techniques for Brick and Stone Masonry Arch Bridges	This report analyzes an extensive sample of 180 repair and strengthening techniques, meticulously selecting the 50 most promising candidates for in-depth exploration. It serves as a comprehensive guide, delving into the effectiveness, advantages and disadvantages, and costs of each shortlisted option, empowering professionals to make informed decisions when tackling masonry arch bridge restoration projects.

4. Research Aim and Objectives

The objective of this study is to systematically gather existing literature and methodologies, conducting a thorough and detailed analysis of published documents and past research on Life Cycle Assessment methodologies for infrastructure. The goal is to draw conclusions and consolidate all existing approaches, with the primary objective of proposing an integrated life-cycle-oriented sustainability assessment to assist in the design of structures. The thesis aims to equip engineers with a tool for designing and constructing more sustainable, high-performance prestressed precast concrete infrastructures, particularly focusing on railway bridges at high altitudes. This emphasis is driven by the significant attention required for maintenance to ensure the provision of adequate functionality throughout their extended service life. In response to the identified knowledge gap and the context presented, this research explores questions related to infrastructure sustainability assessment:

Question 1: *What strategies can we employ to effectively integrate all three dimensions of sustainability into unified sustainability assessment of infrastructure based on ISO 14040 framework?*

Question 2: *Is it possible to break through the hurdles for developing a life cycle assessment methodology, directly aligned with the attainment of the recently established sustainable development goals?*

Question 3: *How existing Multi-Criteria Decision-Making (MCDM) techniques applied in sustainable design can be enhanced to effectively grapple with the inevitable aspects of expert subjectivity, leading to reliable project evaluation and selection?*

Question 4: *Are there critical differences while assessing the design of maintenance- intensive structures in harsh environment of high altitudes from a crucial perspective or through one-dimensional approaches?*

This study introduces an expanded LCA based methodology grounded in the ISO 14040 standard, adapted to facilitate a comprehensive sustainability assessment and design for resilient structures. Through its application to various bridge designs in the Himalayan region, we establish a pathway for making sustainable infrastructure decisions that take into account environmental, social, and economic factors.

Following shall be the objectives established for this study:

1. To examine the available literature on contemporary trends in sustainability assessment methods applied to evaluate infrastructure. The emphasis is placed on both the utilization of Multi-Criteria Decision-Making (MCDM) techniques and the specific criteria employed to define sustainability.
2. To study the impact of environmental, social and economic criteria on the life cycle of prestressed concrete railway bridges in the Himalayan region (through a case study of J&K) on the methodological basis of standardized environmental LCA.
3. To identify and propose a methodology to study the economic, environmental and social (integrated as one) life cycle assessments of the structure based on ISO 14040.
4. To expand the current fuzzy Analytic Hierarchy Process (AHP) methodologies employed in Multi-Criteria Decision-Making (MCDM) assessments into a neutrosophic environment. This extension aims to determine the relevance of criteria,

accommodating non-probabilistic uncertainties inherent in decision-making processes.

5. To employ the established sustainability assessment methodology in choosing design alternatives for a structure in a high-altitude environment, taking into consideration their respective sustainability performances.
6. Through a case study, assess the impact of economically, environmentally, or socially focused maintenance strategies on design choices. Compare the outcomes of these one-dimensional approaches with the comprehensive approach that are to be proposed in the study.

5. Significance of the Proposed Work

The proposed thesis work is expected to contribute valuable insights into the environmental impact and sustainability of prestressed concrete railway bridges in the Himalayan region. The outcomes have the potential to influence industry practices, policies, and contribute to the broader goal of sustainable infrastructure development in environmentally sensitive areas. In addition major outcomes expected are:

- It is proposed to study the design of a pre-stressed concrete railway bridge in the Himalayan region of J&K and to construct the proposed methodology required for the sustainable design approach.

- It is anticipated that the results of this study will serve as a recommendation for decision - makers for selecting the most LCA-feasible proposal to minimize the impact on environment.

6. Proposed Month-wise plan of work and targets to be achieved

Sl No.	Activities	Duration											
		Jul-23 to Dec-23		Jan-24 to Jun-24		Jul-24 to Dec-24		Jan-25 to Jun-25		Jul-25 to Dec-25		Jan-26 to Jun-26	
1	Thesis Proposal defense												
2	Extended Literature Review												
3	Questionnaire designing												
4	Pilot testing and refinement of questionnaire												
5	Data collection												
6	Data preparation												
7	Data analysis & Results												
8	Report writing												
9	Thesis Writing, Publications and Other Requirements												
10	Thesis Submission												